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An Improved Control Techniques for DC Microgrid Operation

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ABSTRACT

DC microgrids are the most well-known method for integrating multiple renewable energy sources. The current sharing among distributed resources must be managed, and the DC bus voltage must be kept stable, to control the power flows in DC microgrids. Voltage droop control has been employed to meet these control objectives. When droop control is used in DC microgrids, the DC bus voltage's stability and the capacity to share current across dispersed resources must be balanced since bus voltage variation increases as current sharing gets closer to set points. The basic control system of DC microgrids must guarantee correct load sharing among converters, minimum circulating current between converters with equal load current sharing among sources, and low voltage deviation, The adaptive droop controller, which is novel and innovative, is intended to address the issues with the standard droop controller. To do this, the droop parameters were reviewed online and modified using the primary current sharing loops to reduce the deviation in the load current sharing. The second loop also moved the droop lines to eliminate the DC microgrids' bus voltage fluctuation. The suggested algorithm is tested using a range of input voltages and load resistances. To demonstrate how well the given technique performs in comparison to traditional droop control, the appropriate model is developed in MATLAB/SIMULINK and used to confirm the accuracy and effectiveness of the proposed control strategy, in the future work development of a control system for buck-boost for different applications a DC microgrid with different types of sources.

Keywords: Circulating current, DC microgrid, Droop control, Distributed energy, Adaptive droop control

1. INTRODUCTION

The development and evolution of the smart grid are envisaged to coincide with the plug-and-play integration of the fundamental power system paradigm known as microgrids. Microgrids are specifically small-scale, low-voltage power supply networks intended to meet the electrical needs of a single small community, such as a college campus, a shopping mall, or a trade estate. Microgrids are capable of dynamically coordinating local generation and demand on their own [1]. It has two modes of operation: linked to the grid and islanded. In microgrids, distributed energy resources that are non-traditional or renewable are typically used as power producers or micro sources [2]. While using such renewable resources would have a positive impact on the environment, there are also new challenges.

Distribution-level DC microgrids are currently evolving. The growing renewable energy technologies such as PV solar, hybrid vehicle, storage batteries, and ultracapacitors are all DC-based, which effectively supports a DC microgrid paradigm that forgoes unnecessary conversion steps. Electronic DC loads make up many of the new loads. A microgrids is made up of multiple parallel-connected converters that distribute current across various distributed resources at a single DC bus, as illustrated in Fig. 1[3]. Due to the possible advantages of DC systems over AC technology, DC microgrid is now a viable option for meeting the load demands and anonymously expanding DC applications [4]. Achieving efficient and tolerable output voltage regulation for the current shared across the converters is the main goal of current sharing control of multi-converters in the DC microgrid [5].

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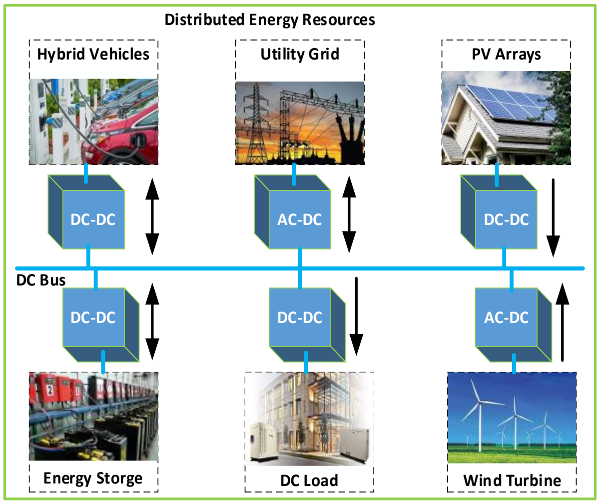

Fig 1: different power sources DCMG configuration.

Benefits of Distributed Generating Systems:

- It has a lower capital cost because of the small size of the DG.
- May reduce the need for large infrastructure construction because the DG can be constructed at the load location.
- If the DG provides power for local use, it may reduce pressure on distribution and transmission lines.
- With some technologies, it produces zero or near-zero pollutant emissions over its useful life.
- With some technologies such as solar or wind, it is a form of renewable energy.
- Configuration DGs offer many benefits from various points of view, such as expandability, efficiency, reliability, and stability.

Distributed energy storage or a combination of both, challenges the control and stability of the microgrid.

- Because droop controllers do not require a communication link and do not have a single point of failure, they are frequently used in control techniques to maintain the microgrid's proper parameters. This allows for stable and reliable system functioning.
- There are two ways to control parallel converters: droop control and wire communication between converters. If one of the parallel converters of the first type fails, it will have an impact on the other. Additionally, these connections will be expensive.
- Low-cost and highly reliable droop approaches are available. Droop control is effective but has several limitations, such as inaccurate load sharing.

In addition to attaining the required goals, a suitable control mechanism should be able to preserve the system's stability. In DC microgrids, the droop control approach is a well-established tactic that is frequently used [6]. For droop to function, the droop parameters need to be sufficiently large in relation to the line resistances. However, high droop parameter values lead to unacceptably low voltage levels. There is a trade-off between these goals as a result [7]. Droop control, in which each converter is adjusted to maintain the MG voltage, is the most efficient technique for DCMG control [8]. The droop approach is exceptionally reliable and inexpensive. Furthermore, converter connection is not necessary for droop control. Although effective, droop management has various limitations, such as limited accuracy in load sharing because of the line impedance interface with each DCMG converter and voltage deviation [9]. By using an adaptive droop control technique, the bus voltage regulation and power sharing amongst the distributed energy resources in the dc microgrid are less negatively impacted by the above voltage decreases [10].

By using the droop technique, a hierarchical control algorithm lowers the converters output voltage mismatch. There have also been methods published that disregard the influence of connecting line impedances [11-12]. A hierarchical management system that was created to maintain power balance and smooth bus voltage fluctuations during system operation under dynamic load and resource variance [13]. The primary loop is used to continuously update the value of the virtual resistances in the preceding section, ensuring the correctness of load sharing among all converters in DC microgrids [14-15]. The load and/or error of the current or voltage feedback determines the bus voltage variation [16]. The control divided in to proposed adaptive droop controller's major goal was to maintain optimal load sharing while enhancing the performance of the low-voltage DC microgrid and suppression circulating current [17]. To compensate for the bus voltage's difference from the DC microgrids, a second loop is used. To improve and manage the bus voltage utilizing the secondary loop and keep the sharing of the current steady for all converters in the microgrids, the voltage reference of the droop line was adjusted [18 -19].

Achieving effective and acceptable output voltage regulation values for the current shared across the converters is the primary goal of DC microgrid control [20]. The standard voltage droop control approach is the traditional control strategy in DC microgrids [21]. In the literature [22], droop control comes in a variety of forms. The authors discuss five several kinds of droop control for power sharing and bus voltage control. It is easy to put the droop control strategy into practice [23]. The method's drawback, as shown in [24], [25], is that it affects the stability of the DC bus voltage since it improves droop control in current sharing control [26].

As an illustration, excellent current sharing accuracy is achieved at the expense of a high bus voltage deviation when substantial droop resistances are used. Small droop resistances, however, lead to a low bus voltage drop but an inaccurate current sharing [27]. A novel droop technique for DC converter parallel operation was described in [28], which also covered the maximum output current in relation to the current value chosen for regulating the reference voltage of each converter. Only when the source supply has a known rated power does the method perform at its peak level. In [29], an automated droop method for parallel converter operation was described. By putting more demand on the system, the virtual resistances are automatically changed. With this method, load sharing errors are reduced, but as the load grows, bus voltage variance also grows. suggested using an adaptive droop controller with a first-order tracker to obtain the droop parameters. With this approach, there is a low bus voltage variance and a less load sharing mistake.

The major goals of this research project might be summed up as follows:

- Researching the primary difficulties with the parallel DC-DC converters of DC microgrids' traditional droop control.
- Design and management of parallel DC-DC converters for stand-alone use.
- To remove the bus voltage deviation and circulating current between converters with equal load current sharing, a simple and adaptive droop control approach is provided.

The equivalent circuit of the parallel DC-DC buck converters providing power to a resistive load can be modeled as source voltage in series with the cable resistance connected to a common load as demonstrated in Figure 3A and equivalent circuit variable droop control Figure 3B. The voltage level, which utilizes 48 V and is the optimum option for the output low voltage DC transmission system, is a significant factor in determining the system efficiency. Different scenarios portraying the phenomenon are shown in Table 1. When considering the converters supplied with two different source voltages Vi1 and Vi2 and source currents I1 and I2.

The main cause of the current flowing between DC sources is the output voltage variation of the converter. Figure 3A illustrates the parallel equivalent circuit, the cable resistor product can be disregarded in comparison to load resistance RL, which is high. So, it is possible to determine the converter's output current.

$$I_1 = \frac{R_2 V_{i1}}{R_L(R_1 + R_2)} + \frac{V_{i1} - V_{i2}}{(R_1 + R_2)} \quad (1)$$

The major goals of this research project to remove the bus voltage deviation and circulating current between converters with equal load current sharing.

2. *Configuration of Buck DC–DC Converters in DC Microgrid*

This section discusses DC microgrid variable load sharing and recently discussed problems. Figure 2 shows a parallel configuration DC microgrid made up of dc-dc converters, a common variable load, and variable input voltages Vs. Between the source and the low voltage DC bus, a DC-DC buck converter is used as an interface converter.

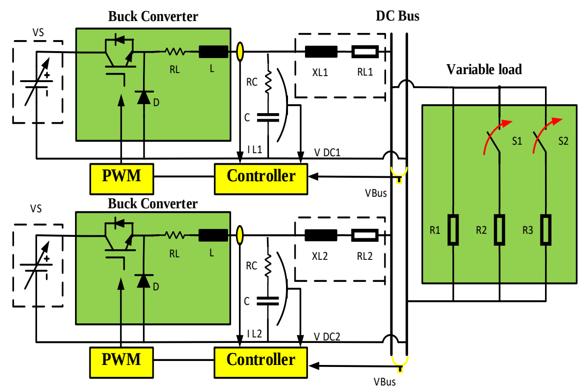

Fig 2: Parallel configuration DC-DC buck converters.

Because of the initial source on the second line, the load current is the first component of the equation on the left side, and the circulation current is the second component.

$$I_2 = \frac{R_1 V_{i2}}{R_L(R_1 + R_2)} + \frac{V_{i2} - V_{i1}}{(R_1 + R_2)} \quad (2)$$

The following equations describe the relationship between nominal voltage and circulating current.

$$I_{C12} = -I_{C21}$$

$$I_{C12} = \frac{V_{i1} - V_{i2}}{(R_1 + R_2)} \quad (3)$$

The sharing of load current and circulating current for parallel DC-DC converters in DC microgrids is discussed. assuming a parallel DR system in a DC microgrid that supplies electricity to a resistive load. If there is an imbalance in the output voltages of the converters when they are linked in parallel, the circulating current problem will occur. A circulating current can start when there is just a little (1%) difference in the output voltages of the converters.

Increased current flow through switches from circulating current raises the ratings and losses of power electronic switches. The converters become overloaded due to the differential in current sharing that results from circulating current. Together, these two consequences will make the system less effective. In this work, the dc grid voltage level is assumed to be 48 V. The ideal choice for Low Voltage LV dc distribution systems is 48 V, which is typically used in the telecommunications sector.

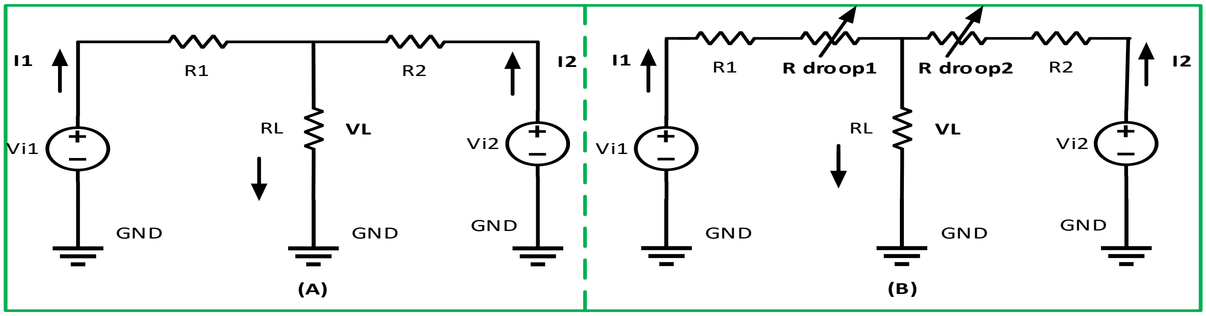

Fig 3: (A) Equivalent circuit. (B) Equivalent circuit with R droop.

Table 1. Different cases study of parallel DC-DC converters phenomena

Case	Input voltages Vi_1 - Vi_2	Cable resistances R_1- R_2	Output voltages V_1- V_2	Output currents I_1- I_2	Output powers P_1- P_2	Circulating currents phenomena
1	Equal	Equal	Equal	Equal	Equal	Absent
2	Equal	Unequal	Equal	Unequal	Unequal	Absent
3	Unequal	Equal	Unequal	Unequal	Unequal	Present
4	Unequal	Unequal	Unequal	Unequal	Unequal	Present

$$I_1 = \frac{\left(R_L + R_{droop2} + R_2\right) - R_L V_{i2}}{\left(R_1 + R_{droop1}\right)\left[\left(R_L + R_{droop2} + R_2\right)\right] + \left(R_2 + R_{droop2}\right)R_L} \quad (4)$$

$$I_2 = \frac{\left(R_L + R_{droop1} + R_1\right) - R_L V_{i1}}{\left(R_1 + R_{droop1}\right)\left[\left(R_L + R_{droop2} + R_2\right)\right] + \left(R_2 + R_{droop2}\right)R_L} \quad (5)$$

Figure 3B illustrates the parallel equivalent circuit with R droop, the calculated converters' output currents are provided as equations (4,5)

The following equations describe the circulating current.

$$I_{C12} = -I_{C21} = \frac{V_{i1} - V_{i2}}{\left(R_1 + R_{droop1} + R_2 + R_{droop2}\right)} \quad (6)$$

On the other hand, this is not workable in real life. To obtain the desired load sharing, each converter's reference voltage can be adjusted. To do this, R droop, a fictitious resistance, is used to change the reference voltage of each converter. It is possible to write the related equations as

$$V_{DC\,new} = V_{1\,ref} = I_1\left(R_1 + R_{droop1}\right) + R_L I_L \quad (7)$$

$$V_{DC\,new} = V_{2\,ref} = I_2\left(R_2 + R_{droop2}\right) + R_L I_L \quad (8)$$

Can be seen that by controlling the R droop value by equations (7,8) the reference voltage can be controlled.

3. Traditional Droop Control

In this diagram as shown in Fig 4, r and L stand for the equivalent line resistance and inductance, respectively, from the distributed resources to the load bus, V_{ref} for the voltage source reference, and Rd for the droop resistance. It should be noted that the droop resistance Rd is a virtual value that may be changed to alter the current flow from the distributed resources. This shows that the desired current sharing can be done by adjusting the value of the droop resistance.

$$I = \frac{V_{ref} - V_{Bus}}{R_d + r} \quad (9)$$

The new voltage reference for the converter in the droop control is as follows based on (9).

$$V^* = V_{ref} - R_d * I \quad (10)$$

where a new voltage reference is created for the DC voltage output produced by the power electronic converters by multiplying the current entering the grid by the droop constant. That will allow for the desired power sharing.

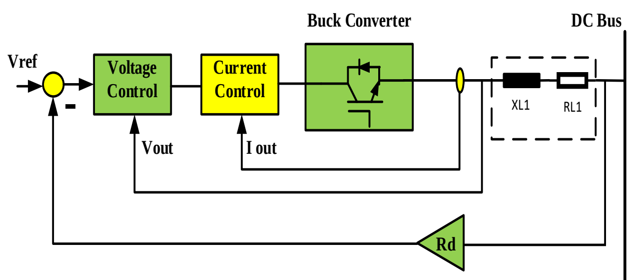

Fig 4: Conventional droop control for distributed resources DC microgrids.

Where I1 and I2 are the currents that feed the load, r1 and r2 are the equivalent line resistances that connect each power generator to the load, and Rd1 and Rd2 are the droop resistances, as shown in Fig. 5.

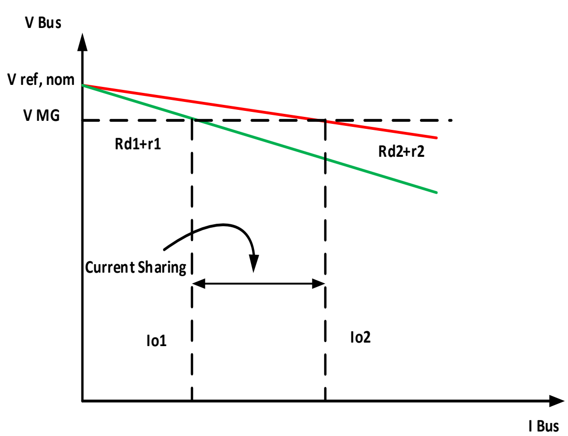

Fig 5: Connection between the virtual droop resistances and the current sharing.

It should be remembered that the droop resistances are movable virtual values. Hence, by controlling these virtual quantities, the current sharing across distributed resources can be done. These amounts are often predetermined dependent on the ability to produce them. The following is the issue of how two converters share to the current load.

$$\Delta I12 = \frac{(R_{d2} + r_1)(V_{ref} - V_{Bus}) - (R_{d1} + r_1)(V_{ref} - V_{Bus})}{(R_{d1} + r_1)(R_{d2} + r_2)} \quad (11)$$

By choosing appropriate droop gains, the current sharing error can be decreased.

4. Principle Adaptive Droop Control DC Microgrid Strategy

Describes the suggested adaptive control system for DC microgrids block diagram as it is displayed in Fig 7. By matching the nominal voltage of the converter, the current sharing accuracy is maximized. To achieve precise current sharing error, each converter's nominal voltage is changed using the local control. Lower nominal and maximum voltage deviation converters share current values more evenly. Due to the bus voltage deviation and current load sharing, the controller is therefore controlled to increase the nominal dc voltage. The reference voltage for each converter is then changed to achieve this using virtual resistance R droop, the reference voltage and power sharing of any converters can be managed by modulating R droop, as can be inferred from equations. (7,8). The converter will have a high nominal voltage value if its voltage deviation is modest. In addition to reducing the current sharing error, the low voltage converter will increase its nominal voltage in relation to the second one. The secondary loop is also employed to lessen voltage variation. Detailed explanations of each control loop are supplied below.

4. 1 The Primary Loop system

For all converters in DC microgrids, the primary loop's goal is to provide correct load sharing. Using the droop diagram in Fig. 5, the proposed adaptive droop's concept is discussed. Where the initial droop characteristic lines are $Rd1$ and $Rd2$ with non-desired current sharing I_1 and I_2 and bus voltage deviation ΔVMG. The droop characteristic lines are suitably moved using adaptive control to the location that satisfies the DC microgrid control criterion. With two separated stages, each movement in this piece can be presented separately. Control of the adaptive current sharing is the initial phase. To update the value of the virtual resistance and improve the power sharing, ±ΔR is added to the conventional droop equation (10)

$$V^* = V_{ref} - (R_d \pm \Delta R) * I \quad (12)$$

A flowchart showing the suggested strategy's steps is shown in Fig. 6. The droop settings need to be fine-tuned to control the source converters and raise the bus voltage such that the output voltage of each converter is identical.

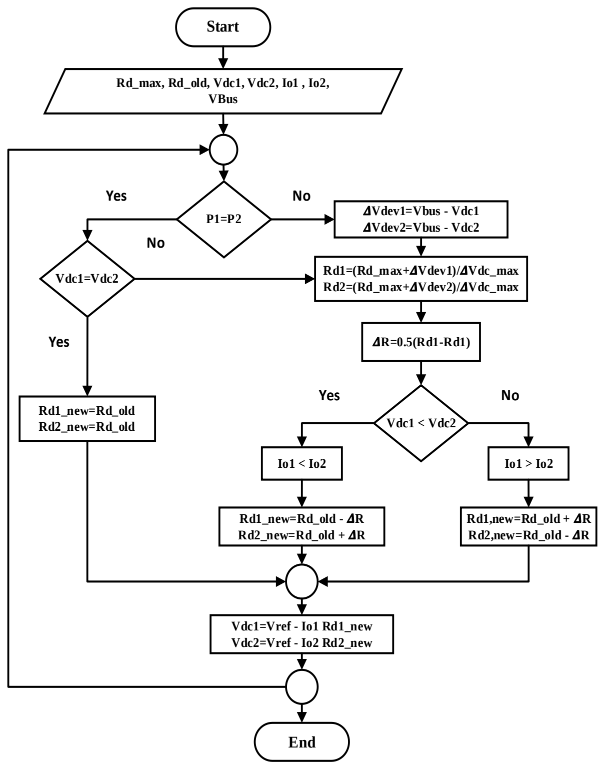

Fig 6: Flowchart droop control technique proposed.

The load current must then be shared almost equally by the proposed control, and as a result, the output voltages of the converters must be the same.

A. AT $V_{differance} = (V_{dc1} - V_{dc2})$ is positive value, $V_{O1} > V_{O2} > R_{d2} > R_{d1}, I_{O,2} < I_{O,1}$,then the following value for Rd droop is provided.

$$R_{d1,new} = (R_{d1,old} \pm \Delta R) \quad (13)$$

B. AT $V_{differance} = (V_{dc1} - V_{dc2})$ is negative value, $V_{O1} < V_{O2} > R_{d1} > R_{d2}, I_{O,1} < I_{O,2}$,then the following value for Rd droop is provided.

$$R_{d1,new} = (R_{d1,old} \mp \Delta R) \quad (14)$$

C. AT $V_{differance} = (V_{dc1} - V_{dc2})$ is zero value, then the following value for Rd droop is provided.

$$R_{d1,new} = (R_{di,old}) \quad (15)$$

4. 2 The Secondary Loop system

The primary loop is used to continuously update the virtual resistances value from the previous section, ensuring the correctness of load sharing among all converters in DC microgrids. The load, as well as any fault in the current or voltage feedback, affects the bus voltage's deviation. In Fig. 8, it is illustrated how a second loop is employed to overcome the bus voltage's variation from the DC microgrids.

Table 2. Parameters DC-DC buck converters

Parameters	Symbol	Values
Ideal voltage DC bus	V_{DC}	48 V
Current rating for source	I_{rated}	20 A
Resistance of line-1	R1	0.1 Ω
Resistance of line-2	R2	0.2 Ω
Inductance of cable line-1	L1	0.2mH
Inductance of cable line-2	L2	0.4mH
Resistance of capacitor 1	r_{c1}	0.03 Ω
Resistance of capacitor 2	r_{c2}	0.03 Ω

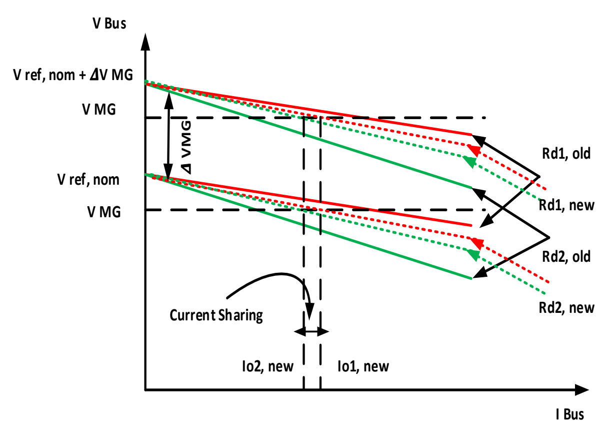

Fig 8: Bus voltage between two DG units is restored.

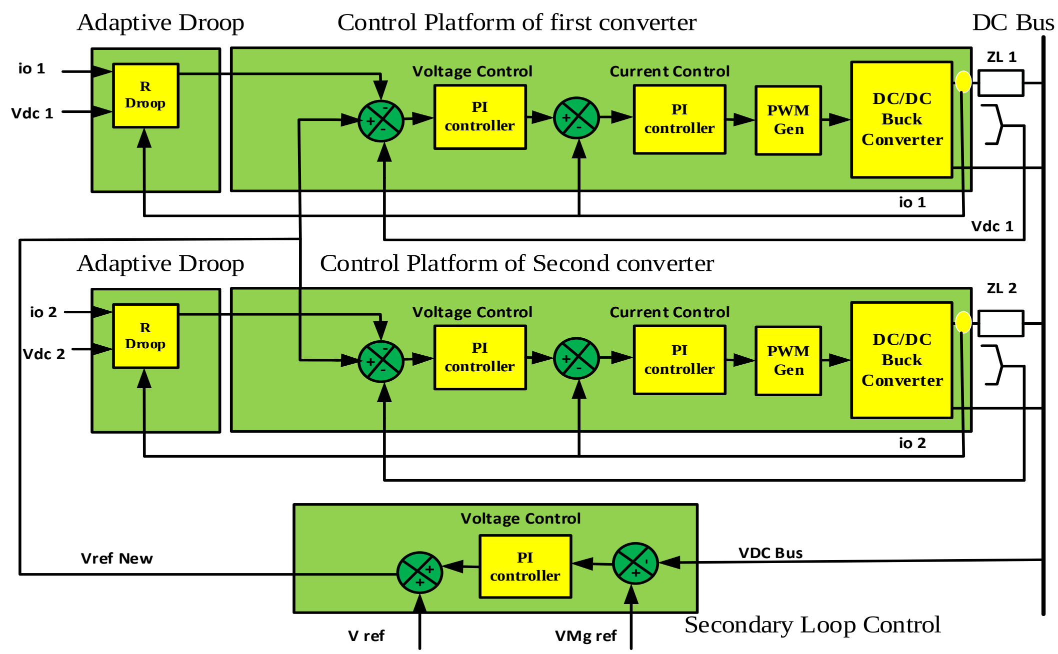

Fig 7: Control diagram of parallel buck converters with adaptive droop control system.

5. *Results And Discussion*

Furthermore, the voltage deviation is smaller than the maximum value even under a severe load. The DC bus voltage is still constant at its nominal value of 48V, as is clear from Fig. 1, despite the variations in the loads at t = 1s and t = 2.5s. The transient response of the suggested algorithm with a load changing from 10 Ω, to 5 Ω, to 3.33 Ω.

I. Constant droop gain

Low virtual resistance R_d = 0.3 Ω is used to assess the simulation results for the traditional droop controller. As shown in Fig 9. The transient response Low virtual resistance R_d = 0.3 Ω with a step load change from 10 Ω to 5 Ω and 3.33 Ω and step change in the input voltage.

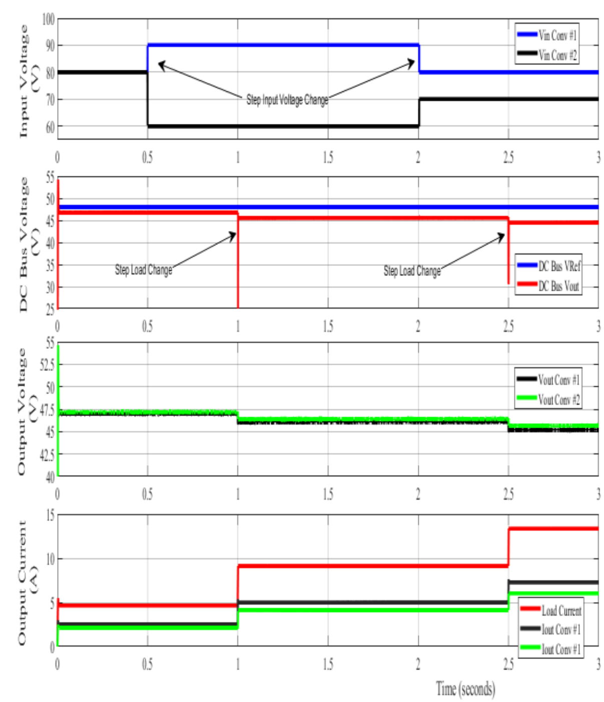

Fig 9: The transient response Low virtual resistance R_d = 0.3 Ω with a step load change from 10 Ω to 5 Ω and 3.33 Ω and step change in the input voltage.

II. Adaptive droop gain

The proposed droop control method is examined and tested in the same operational settings. Fig. 10 shows the transient response adaptive droop control with a step load change from 10 Ω to 5 Ω and 3.33 Ω and step change in the input voltage. Results of the responses for the load current, voltage, and correct effective current sharing.

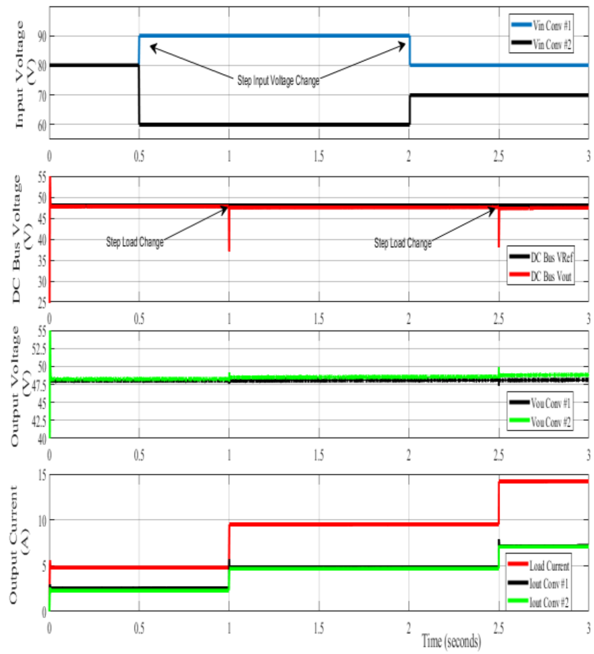

Fig 10: The transient response adaptive droop control with a step load change from 10 Ω to 5 Ω and 3.33 Ω and step change in the input voltage.

Comparison between two methods

Tables 3, 4, and 5 present the simulation findings for the load sharing error and circulating current under various cable resistance situations, varied loads and cable resistances and varying source voltages and loads. Figure 11,12 Comparison between Constant droop gain and adaptive droop gain with a step load change from 10 Ω to 5 Ω and 3.33 Ω and step change in the input voltage.

Table 3. Comparing between two methods with a step change in load resistance 10 Ω

Method	V Bus (V)	I bus (I1, I2) (A)	Δ I Circulate %	Δ V Bus %
Constant droop gain	46.73	4.674 (2.55,2.124)	9.11	2.65
adaptive droop gain	47.77	4.777 (2.511,2.266)	5.13	0.48

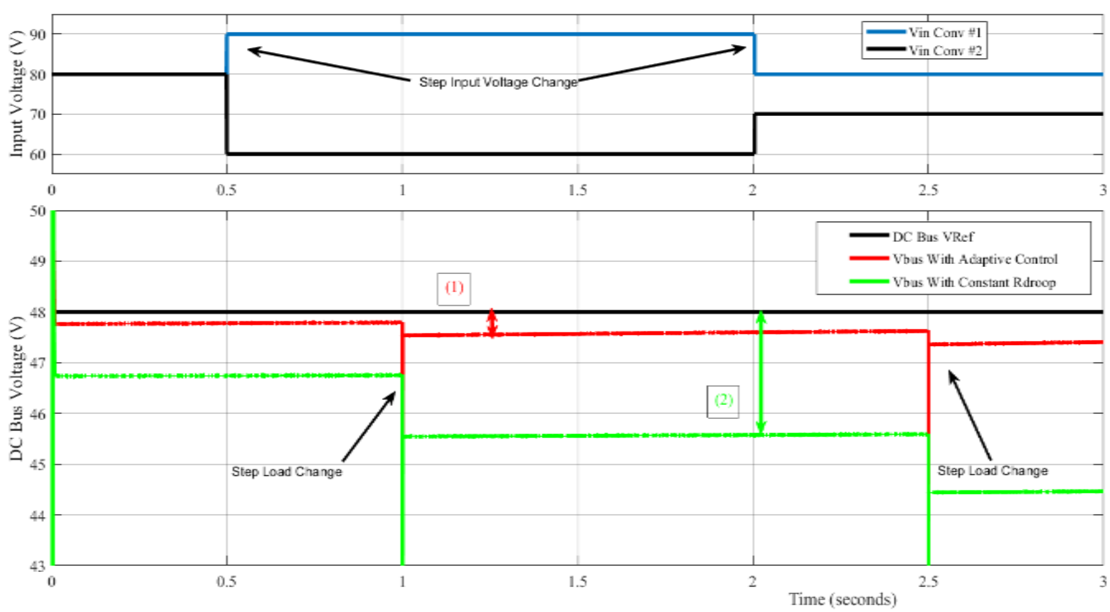

Fig 11: Comparison deviation voltage bus between Constant droop gain and adaptive droop gain with a step load change from 10 Ω to 5 Ω and 3.33 Ω and step change in the input voltage.

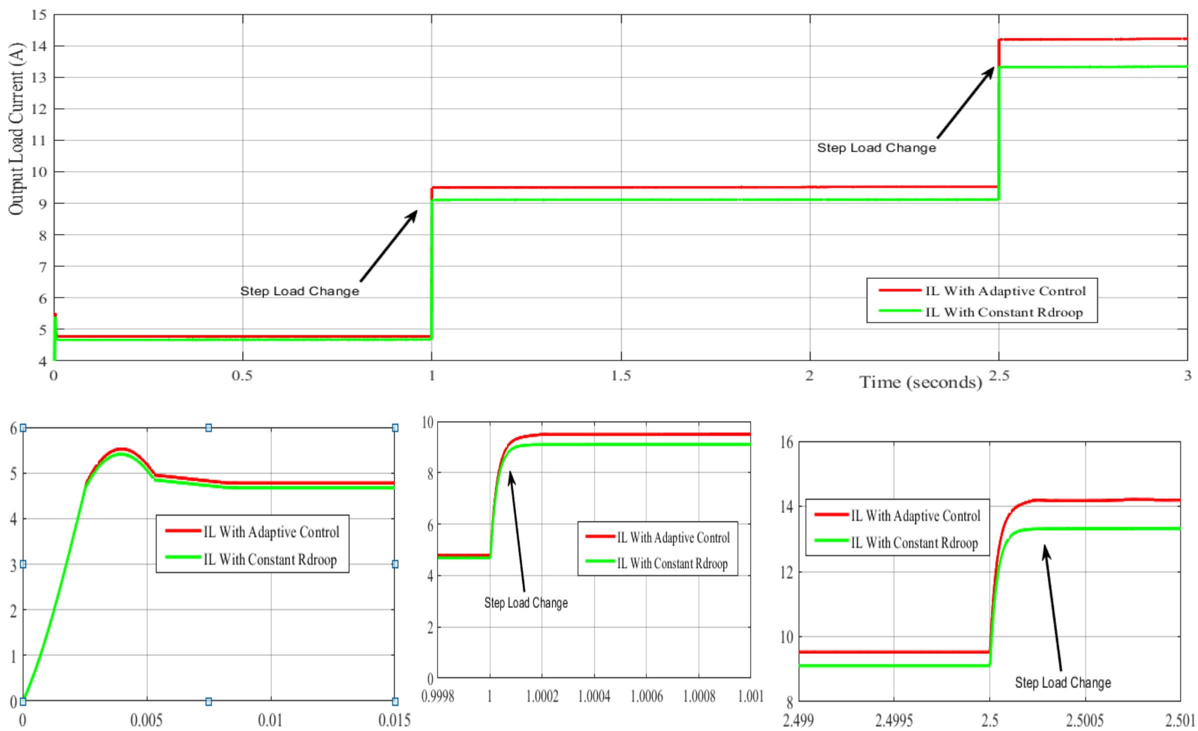

Fig 12: Comparison load current between Constant droop gain and adaptive droop gain with a step load change from 10 Ω to 5 Ω and 3.33 Ω and step change in the input voltage.

Table 4. Comparing between two methods with a step change in load resistance 5 Ω

Method	V Bus (V)	I bus (I1, I2) (A)	Δ I Circulate %	Δ V Bus %
Constant droop gain	45.56	9.108 (4.975,4.132)	9.25	5.08
adaptive droop gain	47.55	9.509 (4.851,4.657)	2.04	0.94

Table 5. Comparing between two methods with a step change in load resistance 3.33 Ω

Method	V Bus (V)	I bus (I1, I2) (A)	Δ I Circulate %	Δ V Bus %
Constant droop gain	44.45	13.33 (7.282,6.044)	9.29	7.4
adaptive droop gain	47.38	14.21 (7.157,7.055)	0.72	1.29

The difference in current sharing amongst source converters, in this instance, it is seen that the value of current sharing varies. At low, medium, and high loading, the highest current sharing error for the traditional droop controller is 9.11%, 9.25%, and 9.29%, compared to 5.13%, 2.04%, and 0.72% for the suggested droop controller. Under different loading conditions, the results show that the current sharing error is relatively low. In addition, the proposed technique allows for the voltage deviation for the traditional droop controller is 2.65%, 5.08%, and 7.4%, compared to 0.48%, 0.94%, and 1.29% for the suggested droop controller. to remain within acceptable bounds even under a variety of operating scenarios with low, medium, and high loading circumstances.

6. CONCLUSION

By choosing the droop coefficients, the classical droop control has been improved in this research effort. To reduce the bus voltage deviation and enhance the precision of the current sharing in droop-controlled DC microgrids. The on-line adaptation method is made to alter the droop control resistance in response to the voltage and current deviation. The suggested control is straightforward and does not call for any added measurements or inter-source converter communication. The simulation test procedures were carried out using MATLAB/SIMULINK, and the proposed control method was tested, appraised, and contrasted with traditional droop control under various operating situations. There are limitations of utilizing fixed droop parameters in DC microgrids. This case presents the adaptive control solution to overcome the limitation to remove the bus voltage deviation and circulating current between converters with equal load current sharing. The results show how the suggested approach improves load current sharing between the converters and lowers output voltage variance, for future work development of a control system with optimization for buck-boost for different applications a DC microgrid with different types of sources and energy storage to see the impact of other sources.

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تحسين تقنيات التحكم لتشغيل شبكة تيار المستمر المصغرة

الملخص:

شبكات التيار المستمر هى أكثر الوسائل المعروفة لتكامل العديد من مصادر الطاقة المتجددة . حيث يجب ادارة التيار الكهربي بين مصادر التوزيع و أيضاً المحافظة على ثبات الجهد للتحكم فى نقل الطاقة الكهربية فى شبكات التيار المستمر المصغرة . لتحقيق أهداف التحكم يتم أستخدام طرق للتحكم فى انخفاض الجهد . عندما يتم أستخدام التحكم المتدلى فى شبكات التيار المستمر المصغرة ، يجب العمل على أستقرار مشاركة التيار الكهربى و ثبات الجهد عبر مصادر التوزيع نظراً لان زيادة الانحراف فى الجهد تكون عند اضافة حمل جديد يؤدى الى زيادة فى التيار الكهربي . تهدف وحدة التحكم المتدلى التكيفي ، و هى وحدة جديدة و حديثة ، لمعالجة مشكلات وحدة التحكم المتدلى التقليدية . للقيام بذلك ، يتم تعديل قيم المعاملات باستخدام الخوارزمية المقترحة تلقائياً و يتم استخدام الحلقة الاولية للتحكم فى تقليل انحراف مشاركة التيار الكهربى .ثم أستخدام الحلقة الثانية للتحكم لازالة أنحراف الجهد و الحفاظ على جهد الناقل عند القيمة الاسمية. تم اختبار الخوارزمية المقترحة تحت ظروف تشغيل مختلفة مثل التغير فى جهد الدخل و الحمل عند قيم مختلفة. لتوضيح مدى جودة أداء التقنية المحددة مقارنةً بالتحكم التقليدي المتدلى ، تم تطوير النموذج المناسب في المحاكاه واستخدامه لتأكيد دقة وفعالية استراتيجية التحكم المقترحة.