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IoT Based Distributive Control of Parallel Connected Sources in Stand-Alone Microgrid

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Abstract:- **Circulating currents in a DC micro-primary grid should be reduced to improve load distribution among sources and voltage management. Several centralized and decentralized control schemes have been proposed in the literature as remedies for the problem. A high bandwidth communication link can assist centralized design in achieving the desired result, but a single point of failure can negatively impact performance and reliability. Due to their ignorance of the parallel-connected sources, microgrids in decentralized designs cannot offer simultaneous current sharing and voltage management. This study solves the challenge with a distributed control system for parallel connected sources in a dc micro-grid.**

Keywords— Microgrid, DC-to-DC Converters, Circulating currents

I. INTRODUCTION

Microgrids are the modern form of self-managed grids that may correctly generate, save and consume electric-powered electricity. Microgrids have their renewable energy sources (RES) and might work in grid-related and islanded modes. In DC microgrids, the road to distribute power is DC. When considering that, the maximum of the RESs (photovoltaic, windmills, fuel cells, batteries, etc.) are dc or dc pleasant assets without delay. The combination of RESs with the dc micro-grid could be relaxed. At the load facet, the general public of the masses (computer systems, led lighting, ups, variable frequency drives, etc.) can function directly dc. In dc micro-grids, the required number of dc-to-dc converters is reduced, which reduces conversion losses. Dc micro-grids are an appealing alternative for effectively producing and consuming electricity since they donot have skin impact, frequency synchronization, or power issue problems. This inspired us to create a DC micro-grid. A micro-grid is a group of linked loads and distributed energy sources that may be controlled as a single entity in respect to the grid. It may operate in grid-connected or island mode by connecting into and out of the grid. Customers may become more dependent and resilient to grid failures by utilizing micro-grids. Local power-producing resources, such as conventional generators, renewable energy sources, and storage, can sustain the local grid's operation when the larger system breaks down or, in the case of remote locations, there is no connectivity to the larger grid. Additionally, contemporary microgrids enable the cooperation of nearby resources to save costs, increase the lifespan of energy supplies, and earn cash through market involvement. [1]

Microgrids provide various services to businesses, organizations, communities, and other clients. Here are eight key advantages of micro-grids, from cutting energy bills and fostering social cohesiveness to keeping the lights on during a storm. Energy resilience and electrical reliability go hand in hand. While dependability refers to the capacity to keep the lights on in the event of a power loss, resilience is the ability to prevent power outages in the first place or to recover swiftly if they do occur.

One benefit of microgrids that developed after Superstore Sandy was resilience. Since then, several less severe storms have highlighted its significance. In certain cases, a microgrid may quickly restore power to a whole building or company with no noticeable impact on the people within. In other situations, a microgrid is set up to restore a facility's key functions. A college campus micro-grid may be set up to restore energy to research labs and dining halls but not to academic offices outside as a result. The institution can sustain a basic and essential level of service if vital activities are up and operating. The plant didn't have to completely shut down while the central grid was fixed, allowing it to rapidly restart normal operations [2]. Utilities are aggressively looking at developing micro-grids at their central offices to restore energy to customers following a large outage swiftly. The utility companies would coordinate staff and information from these electrified command centres. Micro-grids may bring in money while also giving customers a discount. They successfully regulate their energy supply, which allows them to save money. They make money by reselling goods and services to the grid. Customers now have access to never-before-seen amounts of power in the energy industry. Thanks to these micro-grids, they can now produce, manage, and use energy.

Micro-grids can make money by providing extra services to the main grid. Frequency control and spinning reserve are two ancillary services that assist the grid. The sophisticated micro-grid controller that runs the system can take advantage of this instability on behalf of its consumers. The micro-grid achieves this by synchronizing the functioning of its assets with shifts in the cost of power across the whole grid. When grid energy demand is high, and grid prices are high, the controller may instruct the micro-grid to use its resources to avoid paying the higher costs. If the micro-grid has extra capacity, it could sell it to the grid.

The micro-grid enables short- and long-term pricing planning since it uses its assets to create value for its consumers steadily. The intricacy of the micro-grid controller and regional wholesale market rules will determine how far it can go. Micro-grids may benefit financially from participating in utility demand response programmes and national and state clean energy efforts, such as federal production tax credits and state renewable portfolio standards .Numerous grant programmes are available just for micro-grids. In areas with high electricity prices, micro-grids could be able to offer energy more consistently and at a cheaper cost. Utilizing micro-grids offers customers benefits like reliability and greener energy while lowering costs.

Micro-grids benefit society in a variety of ways economically. They first prevent missed workdays and product loss due to power outages. They also assist a region in wooing prestigious businesses. Third, they keep jobs in the area alive as neighbourhood energy plants. Micro-grids disconnect from the grid and utilise on-site generators to continue serving clients during power outages. [3]

We use IoT for communications. The internet of things (IoT) is a network of real-world objects, or "things," that communicate with other electronic equipment and physical structures over the internet and may share data with them. These devices range in complexity from basic domestic items to sophisticated office equipment. There may be over 10 billion linked IoT devices by 2020, and there may be 22 billion by 2025. IoT has recently emerged as one of the most significant 21st-century technologies.

It is feasible to connect commonplace items to the internet using embedded electronics, such as baby video screens, motors, and kitchen appliances. As a result, communication between people, machines, and things is seamless. Physical things may exchange and gather information without a lot of human involvement thanks to low-cost computers, the cloud, big data, analytics, and mobile technologies. Virtual systems may watch, record, and change every interaction between linked topics in today's hyper-connected world. Even though the actual and virtual worlds collide, they collaborate to make art. [4]

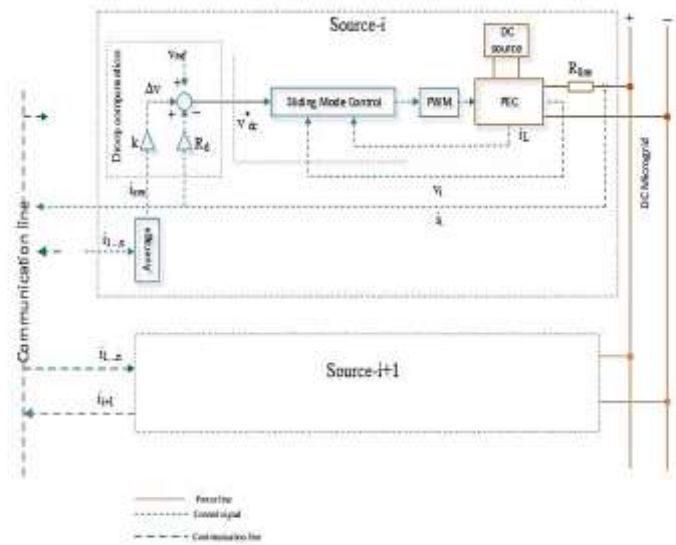

Figure: 1 dc to dc converter with controller

The input line connects the source to the DC to DC converter in Figure 1, and the output line joins the output to the converter. The controller and dc converter is connected, and we are utilizing IoT to communicate with them. We've attached a current sensor, which will monitor the circuit's current and provide data to a controller. It will lower the circuit's circulating current and transfer it to the dc converter through IOT.

II. SYSTEM MODELLING

Energy electronic converters connect DERs in a DC micro-grid in parallel using a shared bus. It is essential to manage parallel electrical electronics converters to obtain energy from environmentally friendly sources. A DC micro-grid's typical setup is seen in Fig. 2. Current sharing, circulating current reduction, voltage degradation, and DER connections are examples of manipulation goals in a DC micro-grid. With the aid of the provided strategy, we can deal with modern techniques, and signal stability. To share the signal variables linked has been taken into consideration for dispensed power designs [5].

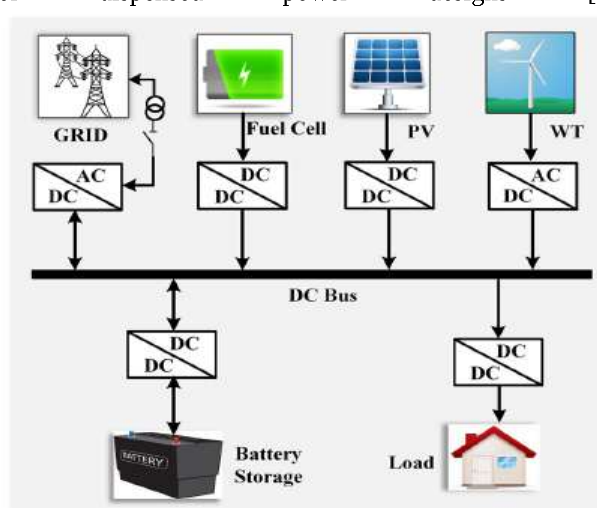

Fig 2. Generic DC microgrid.

A. Circulating Current

The issue of current flow between parallel connections of DC-DC converters with various line resistance and power ratings is covered in this section. We consider a micro-grid consisting of n DERs linked in parallel to share a single load. As mentioned, cable resistance, converter current, and output voltage differences can result in circulating currents.

Circulating currents may impact power and converter switching losses. It also has an impact on the converters' current share percentage. Therefore, circulating currents must be stopped or lowered to achieve the appropriate sharing ratio. A linked connection of DERs is given in Fig 3 for convenience of understanding. DERs are linked to the same bus through DC-to-DC, and the linked circuit is depicted in Fig 4.

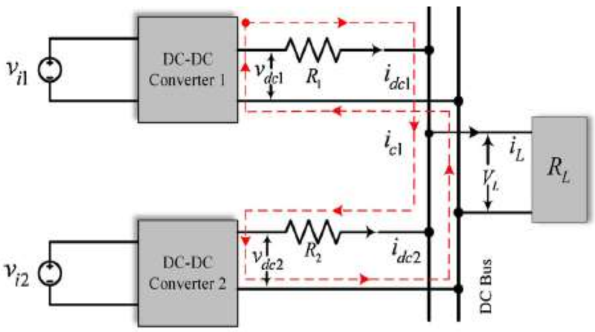

Fig 3. Parallel DC–to-DC converters [5].

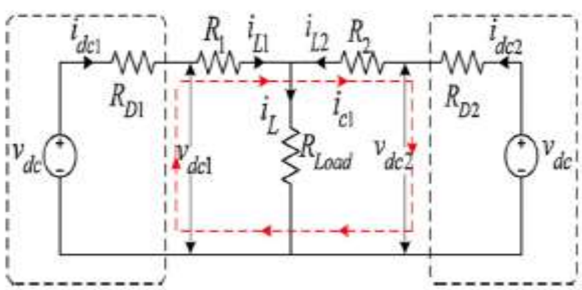
Fig 4. Parallel steady state DC–to-DC equivalent [5].

where V_{dc1}, V_{dc2} R1 and R2 are the signal's resistance and the converters' cables. Circulating currents are caused by the variations in output voltages caused by various ratings of the currents. Here, i_{c1} is a circulating component of i_{dc1} from converter 1 to converter 2 when $V_{dc1} > V_{dc2}$ and similarly, i_{c2} also the components of the current circulating i_{dc2} in this case. In Fig. 4, i_{c1} used to evaluate for the sake of simplicity.

B. Circulating Current Analysis

Figure 4, we can do the following analysis,

$$v_{dc1} = i_{dc1}R + i_L\, R_{load} \quad (1)$$

$$v_{dc2} = i_{dc2}R + i_L\, R_{load} \quad (2)$$

where i_l corresponds to the given load and i_{dc1} denotes the converters current. Mathematical both are written as,

$$i_L = i_{L1} + i_{L2} \quad (3)$$

$$i_{dc1} = i_{L1} + i_{c1} \quad (4)$$

$$i_{dc2} = i_{L2} + i_{c2} \quad (5)$$

$$i_{dc1} = \alpha v_{dc1} - \beta v_{dc2} \quad (6)$$

$$i_{dc2} = \alpha v_{dc2} - \beta v_{dc1} \quad (7)$$

$$\alpha_1 = \frac{R_2 + R_{load}}{R_1R_2 + R_2R_{load} + R_1R_{load}} \quad (8)$$

$$\alpha_2 = \frac{R_1 + R_{load}}{R_1R_2 + R_2R_{load} + R_1R_{load}} \quad (9)$$

$$\beta = \frac{R_{load}}{R_1R_2 + R_2R_{load} + R_1R_{load}} \quad (10)$$

where i_{dc1} , denotes current at the load, i_{L1} and the circular component of the current is,

$$i_{c1} = -i_{c2} = \frac{v_{dc1} - v_{dc2}}{R_1 + R_2} \quad (11)$$

$$= \frac{i_{dc1} - i_{dc2}}{2} \quad (12)$$

It is noted that the combined results of the two resistors might be negligible because the values are much smaller than the values of the load resistance R_{Load}. Inserting the (12) into (6) and (7) to get,

$$i_{dc1} = \frac{R_2 v_{dc}}{R_2R_{load} + R_1R_{load}} + \frac{v_{dc1} - v_{dc2}}{R_1 + R_2} \quad (13)$$

$$i_{dc2} = \frac{R_1 v_{dc}}{R_2R_{load} + R_1R_{load}} - \frac{v_{dc2} - v_{dc1}}{R_1 + R_2} \quad (14)$$

Equation 2.13 represents the load current (i_{L1}) and circulating currents(i_{c1}) of converter 1, whereas equation 2.14 represents the load current (i_{L2})and circulating current (i_{c2}) of converter 2. The results of the simulation are presented in Fig. 3.

III. SLIDING MODE CONTROL

The non-linear control method known as sliding mode control (SMC) permits a non-linear system to "slide" across a section of its normal behavior by issuing a discontinuous control signal. Utilizing sliding mode control, a flexible structure may be controlled. Since trajectories always go in the direction of a region with a different control structure, the fact that there are several control structures indicates that any of them won't restrict the final trajectory. As opposed to that, it will have slipped along the boundaries of the control structures. The system's sliding motion along these boundaries is referred to as a sliding mode, and the geometric region made up of the boundaries is known as the sliding (hyper) surface [6].

The SM control was created especially for controlling variable structure systems according to its simplest formulation. It is a time-varying state-feedback, technically. Discontinuous control rule that quickly transitions from one continuous structure to another in the state space in response to the system's current state with the goal of coercing the system's dynamics under control to accurately carry out the desired and preset actions. In comparison to other non-linear control systems, the SM control method is also more user-friendly since it has a lot of design flexibility. These characteristics make SM control the perfect choice for non-linear systems, which accounts for its extensive use in industrial applications such as electrical drivers, vehicle control, furnace control, etc.

IV. SIMULATION AND RESULTS

We have seen the simulations and their results for a better explanation of our project:

We build a buck converter circuit, and values for each parameter are shown in Table I and Table II.

Table I: Buck converter parameters

Parameters	**Values**
Source Voltage	100 V
Inductor Value (L)	2.4 mH
Capacitor Value (C)	470 µF
Resistor Value (R)	10 Ω
Frequency (F)	25 KHz

We have designed a sliding mode controller and have set values for alpha and beta to control the current and voltage and minimize the circulating current completely.

Table II: Results after comparison for both sides converter

Parameters	**Source 1**	**Source 2**
Source Voltage	100 V	100 V
Current	2.27 A	2.27 A
Circulating Current	0.002408 A	0.0033 A
Voltage	53.8 V	52.21 V
Load Voltage	49.54 V	
Load Current	4.54 A	

So from the results, we can see that our circulating current is minimized from this controller, which we can also see from Table II results which shows both sides of circulating current and also load current and voltage.

Through the Sliding mode controller, the load current shown in Fig. 10 is now equally distributed on both sides Fig. 5 indicates source 1 and Fig. 7 indicates source 2 current. Thus the circulating current is minimized on both sides, which is shown in Fig. 6 and 8, respectively, for source 1 and source 2. The load voltage is approximately equal to 50 can be seen in Fig. 9.

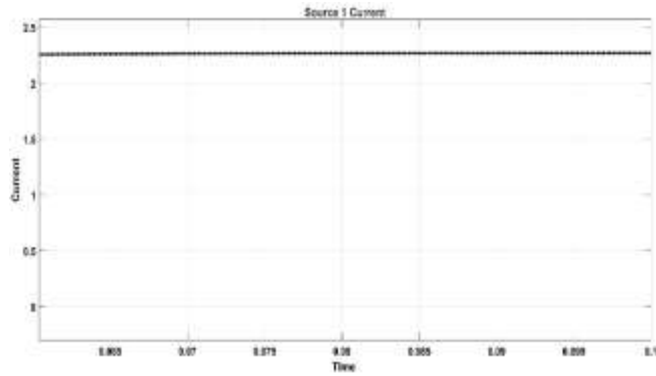

Figure 5: Source 1 current

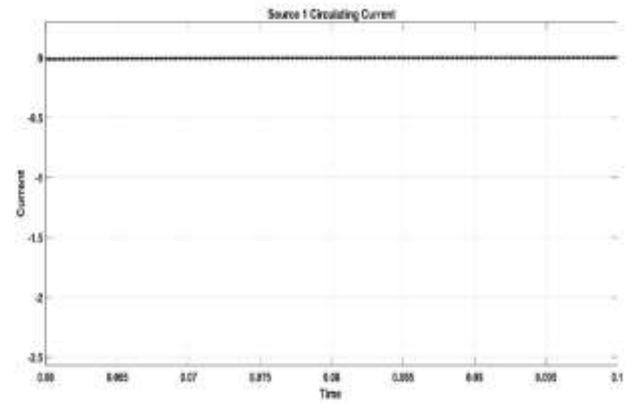

Figure 6: Source 1 circulating current

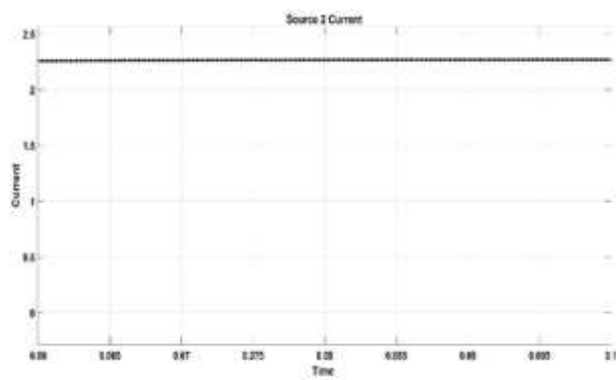

Figure 7: Source 2 Current

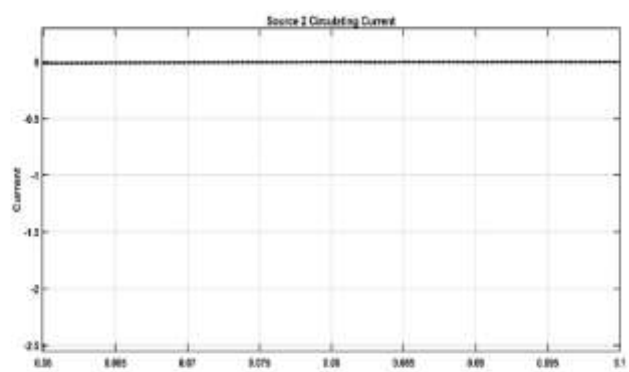

Figure 8: Source 2 Circulating Current

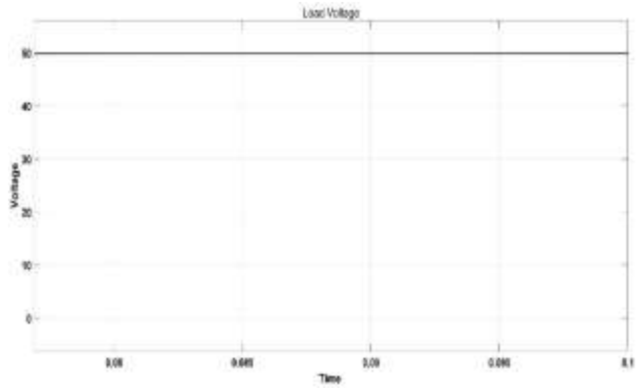

Figure 9: Load Voltage

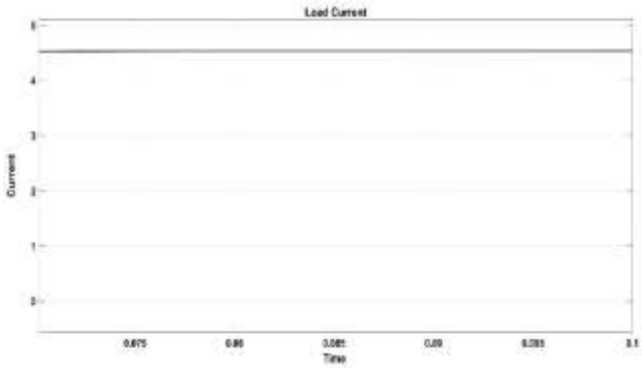

Figure 10: Load Current

V. HARDWARE

The components we used in the project given in Table III.

Table III: Hardware Components

Component	Rating
Inductor	2 mH
Diode	1N4007
Capacitor	2200 µF
Current Sensor	5 A
Load resistance	6 ohm
WIFI module	Node mcu
Arduino	Nano

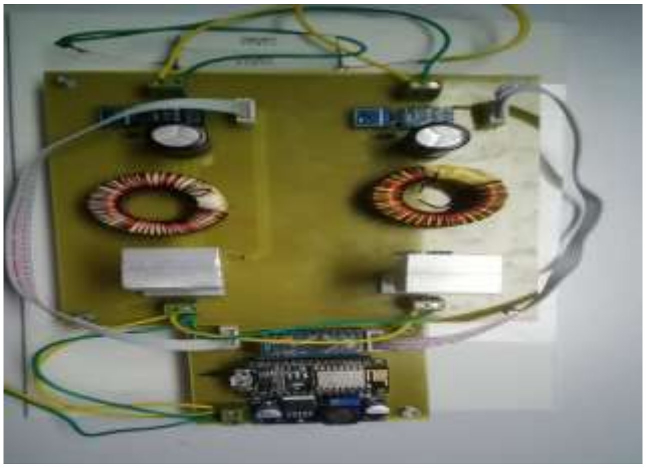

Figure 11: Hardware design

Figure 11 describes the hardware setup which includes a buck converter module which step down the applied voltages to 5V because Node MCU and Arduino Nano operates on 5V which are attached with this buck converter module. In this hardware two buck converters are attached in parallel which step down 12V into required 6V and a load of 6 ohms is attached at the end of the converters. Two current sensors are attached with both the circuits which senses the current from both the converters and delivers this information to the controller. Controller will minimize the circulating current and will improve the voltage regulation among the circuits. It will improve the load sharing among the circuits. Node MCU is attached with controller and circuit which provides all the required information about both the circuits that can also be obtained on mobile application through IOT.

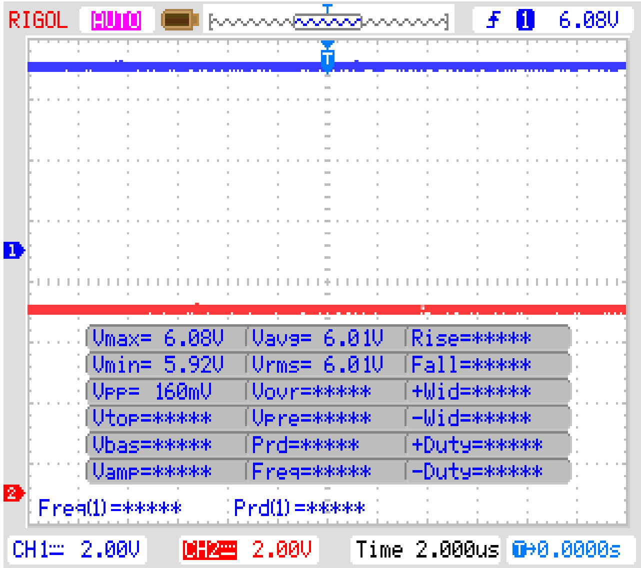

Figure 12: Source 1 and 2 Voltage Scope with Source 1 Measurements

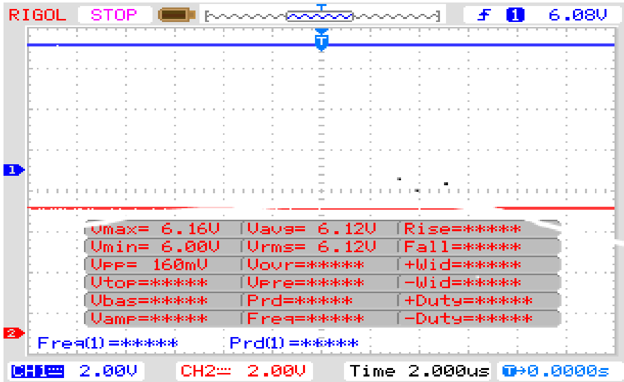

Figure 13: Source 1 and 2 Voltage Scope with Source 2 Measurements

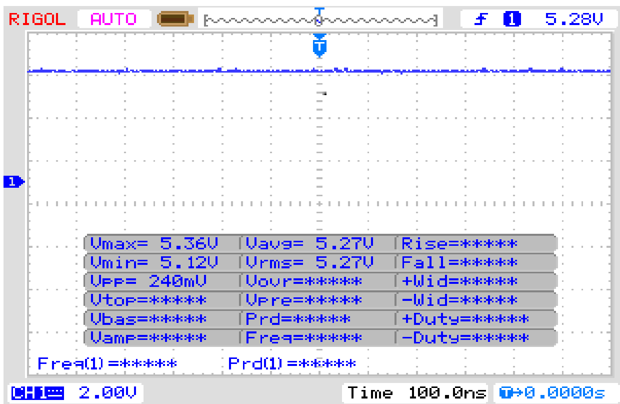

Figure 14: Load Voltage Scope

Figure 14 shows the voltage on the load side, which is approximately equal to 6V as required. Figure 12 shows source 1 and 2 voltage with source 1 measurements; on the other hand, Fig. 13 shows source 1 and source 2 voltage with source 2 sizes. So from the results obtained, we can observe that the voltages at the load side are approximately 6V, and voltage at both sides are equally distributed, i.e., 6V as we required. In the case of current, Our output voltage at the load side is 6V, and we have attached a load of 6 ohms, so by ohm's law V=I/R, we have a current of 1A at load side, which is equally divided as 0.5A at source 1 and 0.5A at source 2.

VI. CONCLUSION

Circulating currents in a dc micro-primary grid should be reduced to improve load distribution among sources and voltage management. Several centralized and decentralized control schemes have been proposed in the literature as remedies for the problem. A high bandwidth communication link can assist centralized design in achieving the desired result, but a single point of failure can negatively impact performance and reliability. Due to their ignorance of the parallel-connected sources, micro-grids in decentralized designs cannot offer simultaneous current sharing and voltage management. This study solves the challenge with a distributed control system for parallel connected sources in a dc micro-grid. This improves voltage regulation and load shedding.

Starting with the implementation on software, a buck converter is designed. Then a controller is attached to this converter to control the current and voltages according to the requirements, and then two of these converters with controllers are attached in parallel.

SM controller is the proposed controller implemented to address the issue of load sharing and voltage regulation. After the SM controller's implantation, the load-sharing problem is solved when the controller minimizes the circulating current. After the software's successful implementation, a PCB layout is designed for the hardware implementation. In the hardware setup, a buck converter module steps down the applied voltages to 5V because Node MCU and Arduino Nano operate on 5V, which are attached to this buck converter module.

Further, in hardware, two buck converters are attached in parallel, which steps down 12V into the required 6V, and a load of 6 ohms is attached at the end of the converters. Two current sensors are attached to both circuits, which sense the current from both converters and deliver this information to the controller. The controller will minimize the circulating current and improve the voltage regulation among the circuits, improving the load sharing among the circuits. Node MCU is attached to the controller and circuit, which provides all the required information about the circuits that can be obtained on mobile applications through IoT. After all this, our problem is resolved using the proposed SM controller.

FUNDING STATEMENT

The authors declare they have no conflicts of interest to report regarding the present study.

CONFLICT OF INTEREST

The Authors declare that they have no conflicts of interest to report regarding the present study.

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