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A REVIEW OF DC MICROGRID FOR INDIAN RURAL HOMES

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Abstract - *With around 237 million people without access, India has the greatest percentage of the world's population without power (International Energy Agency). However, a lot of homes with access to electricity don't have a reliable, constant power source. Most of the Indian households, particularly those in the poor and middle classes, frequently lack access to reliable power. This can be because, despite the power tariff's subsidy, it is not affordable. Power DISCOMs are also hesitant to provide electricity to such residences as doing so would not be profitable to them, given their own precarious financial situations. India seems to be stuck in this logjam as power cannot be generated at much lower costs, even as it depends on environment-unfriendly coal-fired power plants. A dc microgrid for a home with a solar PV, a battery, and an incoming ac grid to drive dc loads can indeed help overcome many a problem. The solar-dc system at the homes can take in energy from or give out energy to the microgrid, thus sharing energy between homes.*

Key Words: **DC Microgrid, Bidirectional, Grid voltage controller, DTMF,IRU.**

1. INTRODUCTION

Socioeconomic development and energy are inextricably linked. According to a recent assessment by the Council for Energy, Environment, and Water (CEEW), nearly half of the homes in six states (Bihar, Jharkhand, Madhya Pradesh, Uttar Pradesh, West Bengal, and Odisha) do not get electricity despite having a grid connection. This demonstrates the urgent need to address the quality, availability, and dependability of the power supply in addition to growing the grid's footprint. There is no evident cause as to why so many homes are still off the grid and why those that are on it experience lengthy periods of load shedding. While power consumption hasn't been rising as quickly, power generation capacity has. Because of this, there is now less of a supply-demand mismatch, and the main cause of the problem is no longer power shortages. According to the Indian Ministry of Power, a hamlet is considered electrified when 10% of its residences are wired to the grid. Despite being a significant concern, this bottleneck might be overcome by simply providing all villagers who reside in a connected hamlet with current electrical connections [1].

Projects to extend the grid to these isolated rural areas are labor and money-intensive. Additionally, the cost of expanding the grid could not be a viable and cost-effective solution because the areas are not heavily populated and have a low demand for electricity [2]. Microgrids were initially developed as a way to address local energy needs by connecting dispersed power sources with distribution networks like local substations without having to extend costly centralized utility grids.

Microgrids are low-voltage power networks that utilize energy sources such as solar arrays, fuel cells, micro-wind turbines, and energy storage systems. Microgrids frequently connect to low or medium voltage distribution networks through a direct connection or an interfacing power converter in order to obtain electricity from the utility grid and transmit power back to the utility grid when there is excess generation [3]. The microgrid maintains its load utilizing a variety of management techniques, like droop control, in the case of a fault by promptly cutting itself off from the utility network. The unique attributes of the micro grid enhance the quality, security, and reliability of the grid's power supply for local customers as well.

The country moves toward becoming completely green when people choose to use energy-efficient DC-powered appliances and power is produced by solar panels on their rooftops. Over the past few decades, appliances in homes and businesses have gradually switched to dc, therefore it is a step forward as we power them with a dc microgrid rather than using individual ac-dc converters. The most straightforward, dependable, economical, scalable, and highly successful solution for providing energy is a DC micro grid with centralized solar production and decentralized storage. The solar-dc system at the homes can take in energy from or give out energy to the microgrid, thus sharing energy between homes [4].

Section 2I is an introduction to the Architecture of DC Microgrid System. Section 3 & 4 describes the Operation modes of DC Microgrid and the Grid Configurations in DC Microgrids. Section 5 is an explanation of the DC Microgrid control strategies. Section 6 deals with the DC Microgrid protection system. Inverter-less 500W system is shown in Section 7. The advantages and disadvantages of DC microgrid system is explained in Section 8. Section 9 gives the conclusion.

2. ARCHITECTURE OF DC MICROGRID SYSTEM

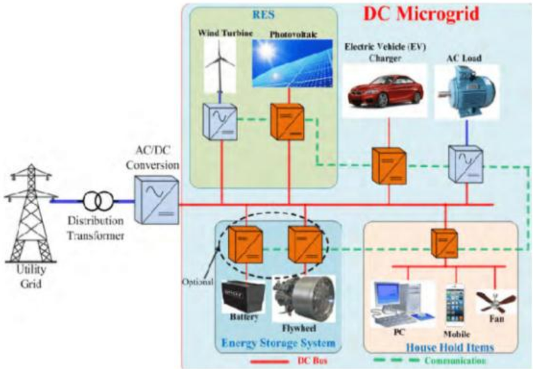

Fig. 1: Building Block of DC Microgrid System [5]

A micro-grid is a collection of interconnected distributed energy resources capable of meeting a considerable amount of internal load demand with sufficient and consistent energy. The building blocks of a DC microgrid system are depicted in Fig. 1. The following are the basic components of the DC Micro-grid system displayed in Fig. 2[6]:

i. *Distributed Generation (DG)*

Distributed Generation is a technique for producing power from modest sources at various grid nodes. These may include geothermal, microturbines, wind turbines, photovoltaic cells, and backup diesel generators. In addition to solar energy, wind energy has become a significant resource in micro grids, with global consumption growing at a rate of about 30% annually.

ii. *Energy Storage System*

Energy storage is a crucial element in making renewable electricity sources a dependable supplement to primary energy sources and assuring the efficient operation of microgrids. Maintaining the equilibrium between power generation and consumption depends on the energy storage mechanism.

iii. *Loads*

Multiple loads are present in a micro grid system, which raises a number of operational, stability, and control challenges. Electrical loads are of two types: static loads and electronic loads. Loads that demand high levels of reliability can be powered by the micro grid.

iv. *Grid voltage controller*

The control process in a DC microgrid should be performed by a combination of multiple controllers working together at different levels, such as the distribution, micro grid, and unit where data acquisition and control signals are transferred. Due to its ability to transfer additional power from the DC bus to the AC grid or from the AC grid to the DC bus, the bi-directional grid voltage converter (GVC) is also a key component of DC micro grids.

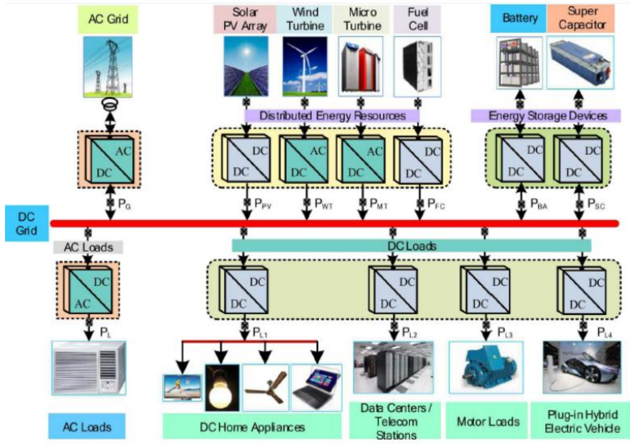

Fig. 2: Architecture of Single Bus DC Microgrid [5]

3. OPERATING MODES OF DC MICROGRID

The controllers for DC micro-grids can be made to work in islanded and grid-connected modes. In grid-connected mode, the grid VSC (Voltage Source Converter) regulates the DC link voltage while in islanded mode, the energy storage device (battery/super capacitor) controls the DC bus voltage [7].

Fig.3 depicts the grid-connected mode, grid VSC balances any power imbalance. Whereas, in islanded mode shown in Fig. 4, power mismatch is balanced by sufficient energy storage. The load shedding controllers are integrated with the loads to turn them on and off , when energy storage is insufficient, in order to balance power and maintain the DC bus voltage at a set level.

i. *Grid Connected Mode*

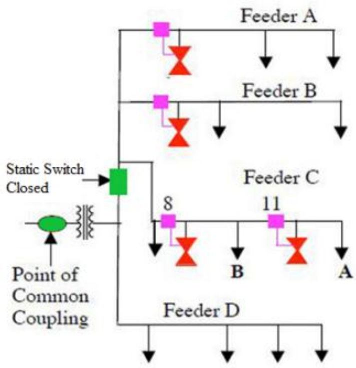

Fig. 3: Grid Connected Mode of Operation of Microgrid [6]

The static switch is closed and the grid is functional in grid connected mode. All the feeders are supported by the utility

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grid, and the voltage and frequency are maintained within the range of grid value power flow, which is determined by the

power generation and load profile. The grid manages the power interchange between the micro-grid and the utility grid[6].

ii. Islanded Mode

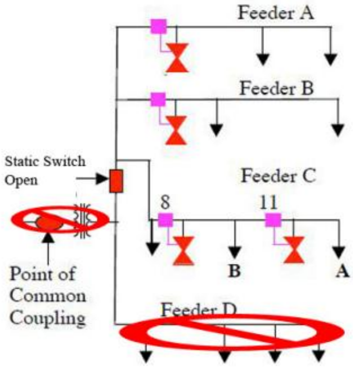

Fig. 4: Islanded Mode of Operation of Microgrid [6]

With the use of distributed generation, micro grids can operate as independent small-scale grids, if the static switch is left open and the utility grid is unable to supply power. Micro sources are supporting Feeders A, B, and C. But feeder D will be dead [6].

4. GRID CONFIGURATIONS IN DC MICROGRID

A DC Microgrid can be set up as a unipolar or bipolar system. In contrast to a bipolar distribution system, which is a two-phase system with three wires, a unipolar (two wire) distribution system only has one voltage level with two wires. However, installing a bipolar(three wire) architecture only costs half as much and allows for twice as much power distribution. A bipolar architecture also offers a lower line-to-ground safety risk since the maximum DC line voltage with respect to ground is half as a result of the neutral point being grounded. The 2-phase DC bipolar architecture gives the flexibility of a wide range of DC voltage levels for effective operation and increased system reliability. The loads can be rearranged to be powered by the working pole that isn't damaged in the event of a two-pole fault [8].

i. Unipolar Configuration

Fig.5 shows a Unipolar configuration where the loads and sources are connected between the positive and negative poles of the DC bus. As the energy is transferred through a DC bus with a single voltage level, the choice of DC bus voltage level is critical in this system.

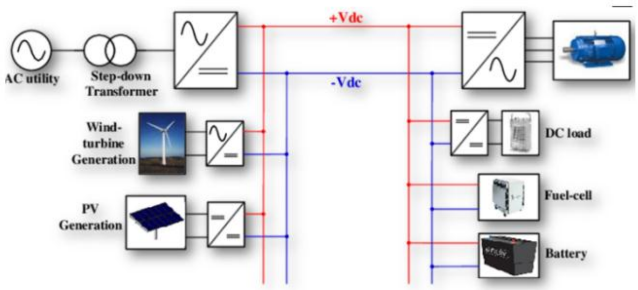

Fig.5: Unipolar Configuration of DC Microgrid [8]

ii. Bipolar Configuration

Fig. 6 depicts the bipolar system, commonly known as the three-wire DC bus system, which consists of +Vdc, -Vdc, and a neutral line. There are three voltage levels: +Vdc, -Vdc, or 2Vdc. In case of fault in one of the lines, power can still be provided by the other two wires (bipolar) and an auxiliary converter. In turn, this improves the system's fault-related reliability, availability, and power quality. Due to its superior power delivery capabilities over unipolar systems, the bipolar DC system is the one that is most frequently used.

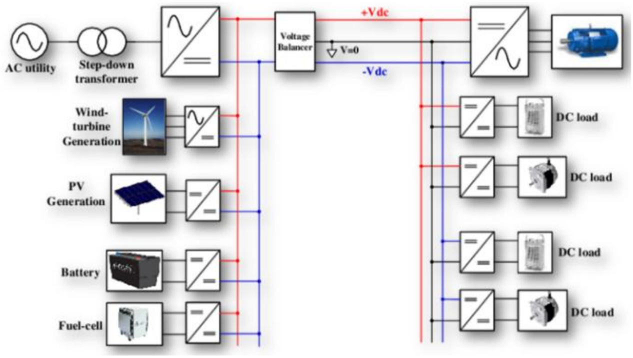

Fig. 6: Bipolar Configuration of DC Microgrid [8]

5. DC MICROGRID CONTROL STRATEGIES

Despite the fact that DC microgrids have progressed in recent years, managing power and controlling DC bus voltage are challenging tasks because of the shared DC bus's connectivity of various hybrid sources and loads. Centralized, decentralized, and distributed controls are the fundamental control systems for DC microgrids[9] .

i. Decentralized Control

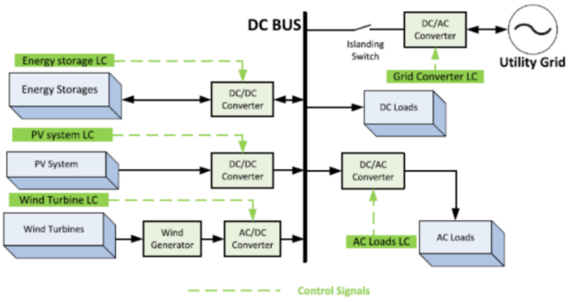

Fig.7: Decentralized control of DC Microgrid [9]

In a decentralized control approach, local controllers rule the associated converters of DC microgrids. The controllers receive a number of locally sensed signals, process them immediately, and produce gate pulses for the converters. The output voltage and current of energy storage devices are detected by the controller and used as input signals to produce gate pulses for the bidirectional DC-DC converter as shown in Fig.7. The most commonly used decentralized controller is the droop approach. It is utilized to achieve decentralized control of each unit, and choosing the droop settings is challenging since they have a significant impact on current sharing, precision, and system stability.

ii. Centralized Control

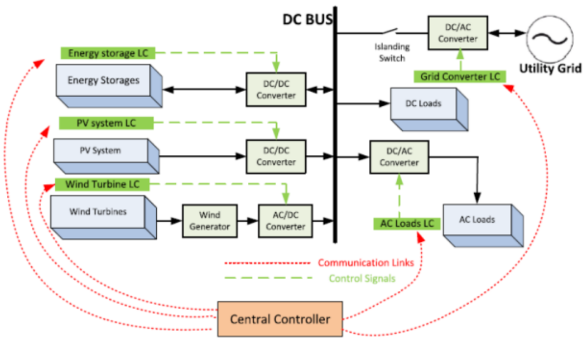

Fig.8: Centralized control of DC Microgrid [9]

The centralized controller depicted in Fig.8 implies that all generating and load units inside DC microgrids are controlled centrally, with the communication link serving as the controller's heart. Data from various units is transmitted to the central control unit via the communication link, and control signals are subsequently transmitted back to each unit. When all of the generation and load data is analyzed by the central controller, load shedding control signals are sent to the non-critical loads if the generation data is inadequate to satisfy all load needs. Both essential and non-critical demands can be met by the centralized controller by managing a variety of energy sources. It has a single point of failure, poorer dependability, adaptability, and scalability, although offering a higher level of observability and controllability. The controller can maintain a consistent state of charge (SOC) for the energy storage while continuously controlling the DC bus voltage.

iii. Distributed Control

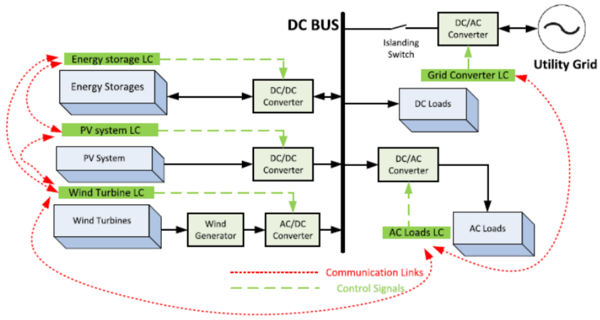

Fig.9: Distributed control of DC Microgrid [9]

The distributed controller, which only communicates with surrounding units through digital communication channels, combines the benefits of both centralized and decentralized controllers (DCLs). In addition to managing each unit connected to DC micro grids, as shown in Fig. 9, local controllers also interact with nearby units to share data such as bus voltage, DG output current, and other relevant information.

6. DC MICROGRID PROTECTION

As depicted in Fig. 10, DC circuit breakers are fitted between charge controllers and the electrical load. The charge controller's integrated polarity safeguard prevents a reverse battery connection. The 20A maximum load current discharge restriction prevents the battery from being over drained with current in the event of user error. To stop DC arcing, DC circuit breakers are placed between the batteries and the charge controller [10].

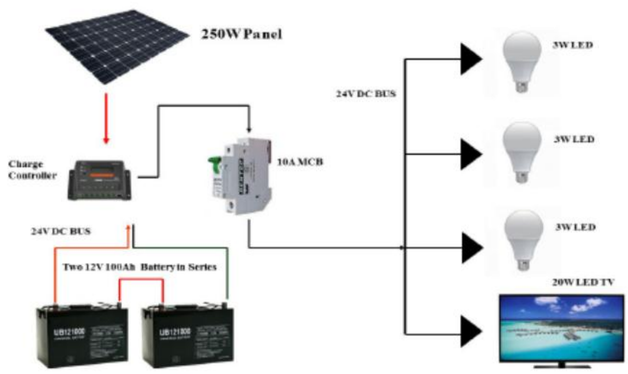

Fig.10: Basic Protection for DC Microgrid [2]

To avoid individual household overloading, a customized rapid response PTC (Positive temperature coefficient) fuse can be installed. Grid downtime is decreased by about 20% when safety equipment is used. . The fundamental safety equipment utilized in DC micro grid is depicted in Fig. 11.

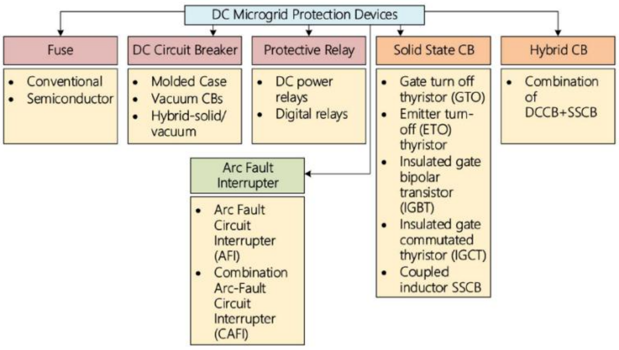

Fig. 11: DC Microgrid protection devices [8]

7. INVERTERLESS 500W SYSTEM

Utilizers can incrementally increase battery and solar capacity with the inverter-less system as needed. Both the solar and battery capacities can be increased, from 125W to 500W and 1kWh to 5kWh respectively. Additionally, this technology allows for future 150W or 500W additional grid capacity expansions. Up to four different homes can each be powered by an inverter-less system. Each home is separately metered and connected via an inverter-free remote unit (IRU). In each of the four residences, the regular line and emergency line can be connected. The inverter-less system controls the load. The communication between the inverter-less system and the rest of the homes powered by it takes place over the power line using DTMF (Dual Tone Multi Frequency), which eliminates the need for cables. By maintaining close proximity between the source and load voltages, the system provides electricity to the load via solar PV, batteries, and the DC grid. The use of a delta adder circuit, which can maintain the right difference between input and output so as to efficiently charge the battery and support the loads, results in a novel method. The system has lower losses since the usual power conversion is not necessary for the higher voltage delivery, which eliminates the losses that would otherwise occur [11].

A priority system makes sure that solar energy is used to its fullest potential before being transferred to batteries and then the grid. By regularly draining the battery when solar energy is not available, it ensures that the solar panels are operating at their full capacity during the day. By reducing the user's reliance on the grid, this lowers their costs. Batteries' health and increased longevity are essential considerations while developing such systems due to their high cost. With significantly lower prices and more efficiency, the inverter-less approach has made it possible for a potent system to supply electricity to every home in India. This basically does away with the requirement for grid connectivity. This system delivers continuous power, and the durable design makes it a very appealing alternative. The Inverterless-500 systems shown in Fig. 12, have been used to power 21 households in Kundithal, Neelgiris. IIT Madras and Cygni Energy Pvt. Ltd. collaborated on this project.

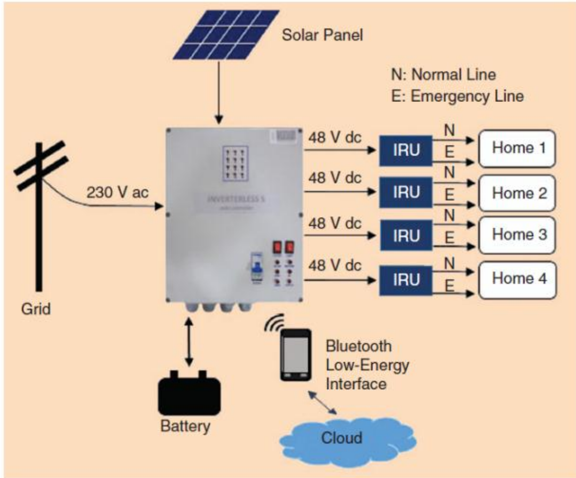

Fig. 12: An Inverterless-500W system with IRUs at each home [11]

8. ADVANTAGES & CHALLENGES OF DC MICROGRID

DC microgrids provide a number of advantages over AC microgrids, such as faster integration of renewable energy sources, superior harmonics mitigation, no reactive power control issues, and direct consumer load connection to the DC bus. DC microgrids, however, can encounter difficult controllers, power imbalances, and high fault current caused by short circuits [12].

A. Advantages of DC Microgrid

- As the DC system has no inductance, the voltage drop in a DC system is lower than in an AC system for the same load, resulting in superior voltage regulation.
- As there is no skin effect, the entire cross section area of the line conductor can be used.
- Extremely efficient, dependable, controllable, and cost-effective.
- There are no difficulties with power quality.
- There are only a few power conversion stages, and there is no reactive current circulation.
- Consumers and companies will pay less for energy.

- Compared to AC power sources, it is significantly simpler to integrate additional DC power generating sources, such as solar panels, fuel cells, and wind turbines, into an existing system to expand its capacity.
- Increasing the number of capacitors in the DC bus will help with ripple management.
- There are no reverse power injections or fault contributions from the dc system into the ac power system.

B. Challenges faced in DC Microgrid

- By merging high-level RES with DC microgrids, DC microgrids' overall inertia is reduced, decreasing voltage control performance.
- Inadequate guidelines and norms.
- Control based on hardware and planning based on software for optimization are essential in DC microgrids.
- A smooth switch from grid-connected to islanded mode is necessary for DC micro-grid operation.
- Arcing phenomena and a long fault clearing time.

9. CONCLUSION

Most of the time, a large part of the Indian population, particularly those in poorer and middle-income households, are denied access to reliable power. Even though power tariffs are subsidized, recent national events and academic research point to affordability as the root of the problem. As a result of their own financial difficulties and the unprofitability of the service, DISCOMs, on the other hand, are unwilling to deliver electricity to such homes. As a result, DC Microgrid proves that it is a practical and affordable solution to this problem. The RES's DC output can be used directly within residential and commercial buildings without having to be converted to AC before being sent into the grid. The availability of DC appliances and power electronics devices improves the DC distribution system's effectiveness. The use of a microgrid in conjunction with renewable energy sources on the load site improves the reliability of electricity in rural areas. The absence of uniformity is the key constraint. Although 48-V dc is widely used in the automotive and telecom industries, there is currently no recognized dc-power standard for home wiring. The IEEE Low-Voltage dc Forum suggested 48-V dc power as a standard for low-power household devices in India. These standards are currently being developed by the Bureau of Indian Guidelines, with a preference for 48-V dc for smaller, lower-power appliances in homes and 380-V dc for larger microgrids with higher power requirements. The International Electrotechnical Commission has established a subcommittee to investigate dc-power requirements for homes and other applications. However, appliance manufacturers and installers are unable to adhere to any authorized standards at the moment. This is the main reason why there aren't many standardized DC-powered DC appliances available. Users will buy once the cost of the appliances are comparable to their ac counterparts. This holds true even when utilizing dc-powered equipment eliminates the need for ac-dc converters, which saves money and enhances dependability. The necessary power-factor correction requirement for ac-powered appliances will also be not required. The implementation of a DC microgrid for houses and the use of rooftop solar panels to power it can, despite these challenges, will be very beneficial for developing nations like India.

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