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DC Bus Voltage Control of Islanded Microgrid using Renewable Energy Based Distributed Generation

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ABSTRACT

DC bus voltage control in DC islanded microgrids is essential for the power quality and reliability. There are various algorithms being used in the literature review to control the bus voltages of DC microgrids. However, most of the research works controlled the generation side that requires high performance devices such as super capacitors etc., On the other hand, battery storage systems are also being used to regulate the bus voltage. In this research work, a separate strategy was developed in which battery storage was implemented at the load side to maintain stability of DC bus voltage. The load management scheme is introduced in which during the voltage instability, the loads are cutoff from the main supply and local installed storage system feed the loads. A particle swarm optimization (PSO) technique was used to optimally decide for the load in watts to be operated. A DC microgrid hardware was designed to test the control algorithm. The loads are not connected to the main system until the power supply is stable again. The load management scheme not only reduces the cost of the system but also stabilizes the overall system with 60% charge available in the batteries using the proposed load management scheme. The results were achieved while performing experiments on developed DC Microgrid hardware.

1. Introduction

The DC bus voltage control in DC islanded microgrids is essential for the power quality and reliability. There are various algorithms being used in the literature review to control the bus voltages of DC microgrids. However, most of the research works controlled the generation side that requires high performance devices such as super capacitors etc., A Model predictive control is used. Controller measures the voltage then generate battery reference current, predict the bus voltage and battery current, then find optimal switching state and apply that to converters [1]. Integral slide mode controller is used with each dc/dc converter to control bus voltage using battery [2]. Discrete time control scheme used for coordination of CGs and RGs. Regulation Is done through coordination while changing load [3]. Finite time adaptive slide mode control is used for bus voltage to reach its

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reference value. Results were compared with the Adaptive Passivity Based Control of dc–dc Buck Power Converter [4]. Load forecast based control, Stabilizing the bus voltages co-designed to balance the SoC levels of ESSs, prioritized (dis)charging controller for ESSs based on short-term energy forecast [5].

ANN based MPC control scheme is used for the stabilization of DC microgrid and the results are compared with conventional cascaded-proportional-integral (PI)-trained ANN control for PV battery-based grid connected DC microgrids [6]. Distributed droop-controlled DC microgrid, Local power controller with economic power dispatch algorithm and voltage controller with average bus voltage observation algorithm are used to regulate bus voltage and power sharing [7]. A model reference adaptive control is proposed as droop controller for voltage stability and current sharing. Results are compared with conventional droop control under different load conditions [8]. Dynamic output-feedback based was used for the developed LTI polytopic system, the results are compared with droop-based control which comprised of current and voltage PI control loop [9]. Droop coefficient correction control is proposed, hierarchical control scheme in which secondary controller is used for the voltage restoration of DC bus [10]. Energy sources are solar and wind, MPPT algorithms are used with multi-agent system, Li-ion batteries are used with bi directional dc/dc converters to stabilize bus voltage using ANN [11].

Hybrid energy storage system including batteries and supercapacitor, traditional droop control is used for converter of supercapacitor which regulate the dc bus voltage, power management system is proposed to ensure the power balance in the system [12]. Decentralized control system, voltage regulation through that controller, results were taken by using different type of loads and different disturbances [13]. DC microgrid EV charging, continuous differential charging (CDC) approach is used for optimal fast charging, The conventional constant voltage (CV) control mode with dual PI controllers is applied for bus voltage regulation [14]. distributed controller, disturbance observer-based control, voltage regulation is done by controlling the load current [15]. MG consist of PV and Battery, bidirectional converter is used with battery, PI double control loop is used for bidirectional converter to regulate the dc bus voltage [16]. DC microgrid consisting of wind turbine, PV modules and Li ion batteries, direct Lyapunov method (DLM) is proposed, control of switching functions for the buck and bidirectional buck-boost DC/DC converters with relying on the dynamic components is achieved through the DLM [17]. DC microgrid with PV and hybrid energy storage system (battery + super capacitor), combined PI and sliding mode control technique is proposed for current sharing and voltage regulation [18].

DC microgrid with hybrid energy storage system, improved PI controller for power sharing and fast bus voltage regulation [19]. sliding mode control is used with bidirectional dc converter of battery energy storage system for bus voltage regulation [20]. distributed control for DC microgrid, cascaded proportional and integral control loops are used for bus voltage regulation [21]. distributed, optimal controller is proposed for dc microgrid, distributed generators only communicate with their neighboring generators [22]. distributed control, A voltage observer is designed to assist the regulation of the microgrid average bus voltage, load current sharing, stability of the system is guaranteed according to Lyapunov stability analysis. [23]. distributed control and discrete time control scheme is proposed for load sharing and bus voltage regulation [24]. Hybrid energy storage system including power batteries and energy batteries is used for bus voltage regulation, double closed loop control is used, power battery is used in outer loop and energy battery is in inner loop for bus voltage regulation based on nonlinear disturbance observer [25].

Dual active bridge converter is used for load current sharing and bus voltage stabilization, moving discretized control set-model predictive control (MDCS-MPC) is proposed and compared with PI controller [26]. sliding mode controller is used for dc to dc bidirectional converter for bus voltage regulation [27].

It is evident from the literature review that conventionally, during the voltage disturbances at busbar due to intermittent operation of renewable resources, compensating devices such as super capacitors, fly wheels and battery storage connected to the centralized systems are used which provides the short-term voltage support. However, the said centralized systems provide voltage stability for a very shorter periods of times. On the other hand, the proposed compensating devices are very costly. In contrary to the compensating devices, the other option is to load shedding and scheduling until the system stabilizes which compromises the user comfort.

1.1 Problem Statement

Due to the 100% operation of renewable energy resources, there is a chance several events of voltage imbalance which cannot be forecasted. Due to multiple sudden power dips due to intermittency, short term stability devices may not support. On the other hand, multiple disturbances in the DC voltage busbar may affect the power quality. Current research works does not account. There is a lack of research work that not only take care of the user comfort but also provides long term stability to the voltage imbalance due to intermittent resources.

A very few research studies are found that address the voltage stability without compromising the user comfort and provides long term stability.

1.2 Contribution

In this research work, a coordinated storage system control scheme is developed that shifts the loads to the designated low-sized storage system during the voltage imbalance. The controller suddenly shifts the load to the coordinated storage as soon as it receives voltage imbalance at the busbar.

2. Methodology

For the voltage stability of the DC microgrids, a novel technique of utilizing a separate battery system with the load is considered. The centralized coordination controller shifts the load to the battery backup in case of voltage variations on the DC busbar. Instead of implementing load shedding, the loads are shifted to the separate battery storage until the voltage stabilizes.

Two intermittent resources, solar PV and DC wind energy are considered with the DC load and designated battery storage. Block diagram in Figure 1 shows the architecture of the microgrid. During voltage instability, centralized controller shifts the load to the designated storage until the voltage stabilizes. Since the load reduces from the main busbar and is shifted to storage, users comfort is not compromised during the entire process. However, for longer periods of instability, the loads are prioritized to be operated on the designated storage using optimization technique which ensures maximum load operation and minimum curtailment under the battery and Solar PV constraints.

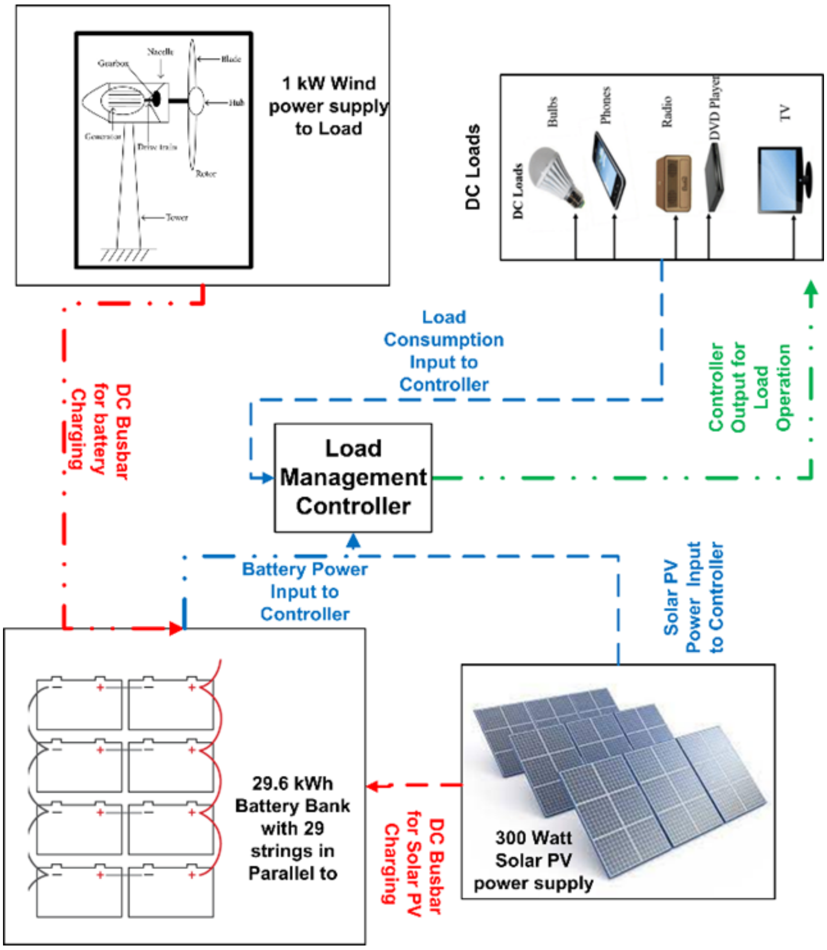

Fig. 1. Block diagram of the developed microgrid architecture

During the disruptions, when battery power supplies the load, an optimal value of power to be dispatched from the battery is essential for longer operation. The optimal dispatch from the battery power allocates the total amount of load in watts that may run based on the constraints. For this purpose, Particle swarm optimization algorithm is designed for battery power dispatch. Based on the results of PSO in watts, the centralized controller prioritized the load to be operated. The load is prioritized based on the user's willingness.

2.1 Particle Swarm Optimization for Battery Power Dispatch

There are different DC loads operational in microgrid. The total available power from the distributed generation sources include power from wind and solar PV. Whereas separately designated battery power is available to feed the load during power disruptions. The power flow balance equation of the complete system is given in Eq. (1).

$$\beta_{wind}+\beta_{solar}+P_{bt}=x_1x_2\ldots\ldots\ldots x_n \tag{1}$$

where β_{solar} is the value for solar power, β_{wind} is the value of wind power, P_{bt} is the battery power and x_1 and x_2 are different DC loads of microgrid.

The objective is to provide optimal values of load to be disconnected from the storage during the lower state of the charge of batteries. The objective function is given in Eq. (2).

2.2 Objective Function

$$\mathrm{Ls_{min}} = \sum_{1}^{n}(\mathrm{Lx_1} + \mathrm{Lx_2} + \mathrm{Lx_3}) \quad (2)$$

where $\mathrm{Ls_{min}}$ is the objective function for minimized load shedding and x_1 and $x_2$and $x_3$are the load reduction values of a a DC microgrid.

To maximize the customer satisfaction, load greater than 5 W should not be curtailed. Here, the critical load is has been considered as PL3

$$x_3 \geq 5 \quad (3)$$

The battery storage is responsible to provide power during disruptions. For reliable operation, the power from the battery must be in between the desired limits mathematically expressed in Eq. (4)

$$-\mathrm{P_{bmin}} \leq \mathrm{P_b} \leq \mathrm{P_{bmax}} \quad (4)$$

The battery power to be dispatched also depends on the available state of the charge. The state of the charge within desired limits is set either to dispatch the battery power or to reduce the load.

$$\mathrm{SoC_{max}} \leq \mathrm{SoC} \leq \mathrm{SoC_{min}} \quad (5)$$

The initial state of the charge of battery can be expressed as:

$$\mathrm{SoC_t} = \mathrm{SoC_t} - \frac{\mathrm{P_{bt}}}{\eta \mathrm{C}} \quad (6)$$

At this time total power dispatch from the battery is zero and can be expressed as:

$$\mathrm{P_{Bt}} \leq 0 \quad (7)$$

The state of the charge of battery when battery is discharging can be expressed as:

$$\mathrm{SoC_{t+1}} = \mathrm{SoC_t} - \frac{\eta \mathrm{P_{bt}}}{\mathrm{C}} \quad (8)$$

At this time the power dispatch from the battery is greater than zero and can be expressed as:

$$\mathrm{P_{Bt}} \geq 0 \quad (9)$$

3. Results

The obtained results are based on optimal load values to be operated attained from the PSO and a DC microgird hardware. The DC microgrid hardware was designed and programmed using Arduino controller. Figure 2 shows the DC microgrid and distributed generation. The load was considered as 25 Watts for this experimentation.

Fig. 2. Microgrid hardware during testing of algorithm

The PSO optimization results can be seen in the Figure 3 and 4. Based on the different values of SoC, PSO decides for the load in watts to be allowed to operate. PSO program was tested while using different values of SoC It can be seen in Figure 3 that total load of 14 watts was allowed to be operated. On an average, the load allowed to be operated remained in between 10 to 15 watts.

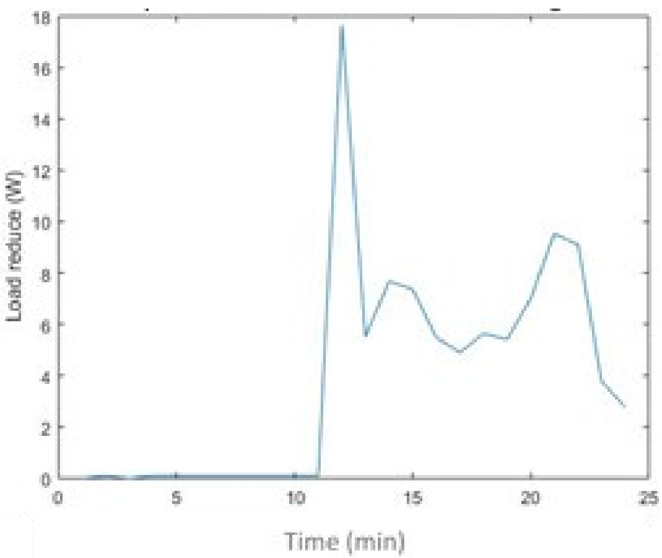

Fig. 3. Optimal values of load to be operated using PSO

Figure 4 of the result shows bus voltage control during the load operation. The bus voltage reduced significantly during the 5th minute due to the change in available power from the solar and wind distributed generation shown in Figure 5. The load operation kept reducing from the main system due to the unavailability of solar and wind power and connected to the local storage. The discussed scenario is intentionally kept as worst to check the controller performance. It can be seen from the load graph that all loads were reduced except the critical load. The overall system performed well with bus voltages controlled in the safe limits under 100% renewable energy penetration level.

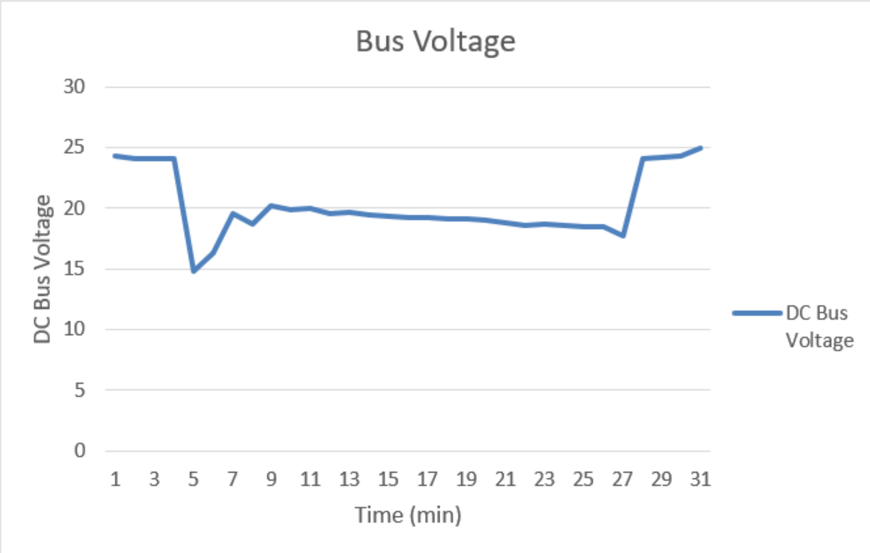

Fig. 4. DC bus voltage of Islanded microgrid

The deviation in the bus voltage occurred due full load operation and low generation thus causing demand and supply mismatch. Figure 6 shows the load operation of the microgrid. As the controller reduces the load, the bus voltage was stabilized under the safe limits as shown in Figure 4 during the 11th min. During the unavailability of solar and wind energy (Figure 5) after the 10th second, the bus voltage again started reducing. At the same time, the other loads were turned off to stabilize the system. It is worth mentioning here that the loads were connected to the local storage systems available that has more than 60% of state of the charge as shown in Figure 7.

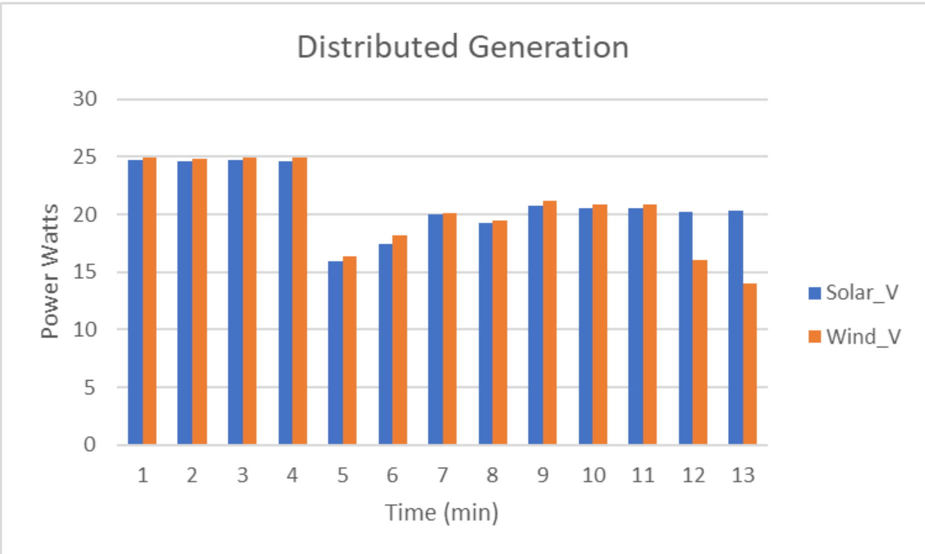

Fig. 3. Distributed generation operation

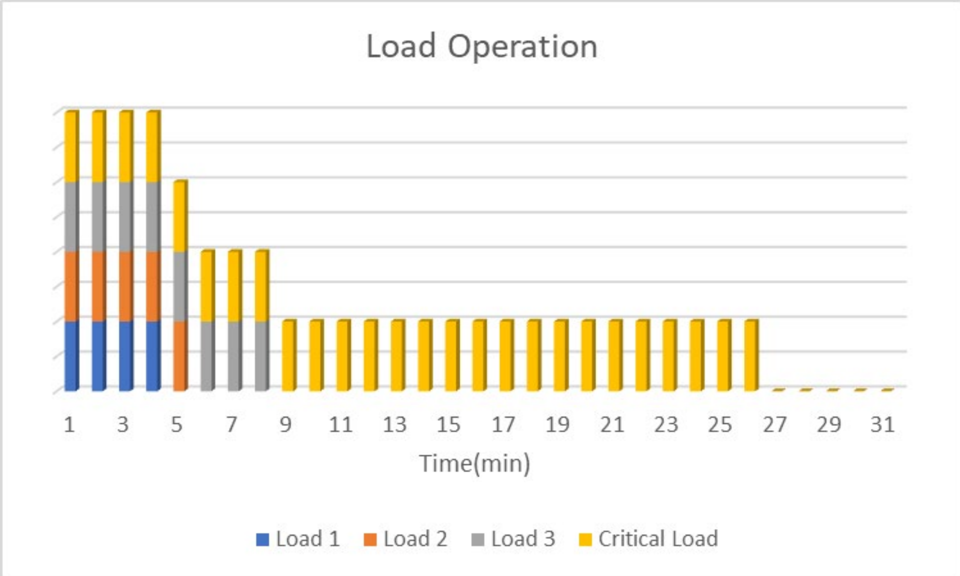

Fig. 6. Load operation of Microgrid

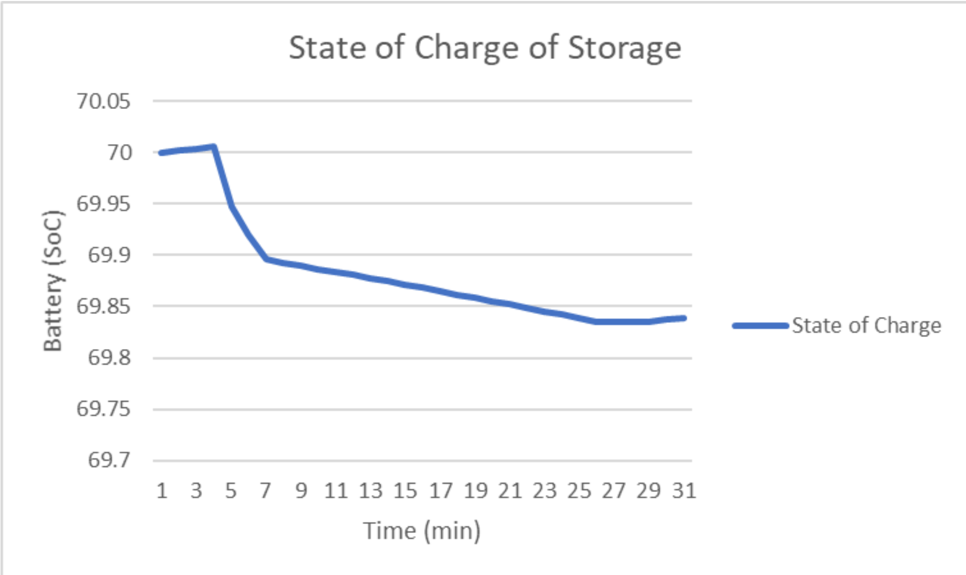

Fig. 7. State of the charge of local storage connected with the load

3.1 Comparison of Centralized and Proposed Storage Technique

Under the proposed system the loads are connected to the dedicated storage that are near to the load and thus less losses occur compared to the centralized storage. The centralized storage is at central location where more cost for the wiring and overall system configuration is required. This distant installation not only increase the cost but also induce losses. Due to having dedicated storage at the load side, the fluctuations in the DC bus are reduced significantly whereas the burden on the storage is also reduced as the controller checks for the available SoC of the storage and connects or disconnects the load.

4. Conclusion

To economically maintain the bus voltage of a DC microgrid with 100% renewable resources penetration, the local storage coordination with load management can be an economic solution at the load side instead of complex generation controls. Since the local storage is considered where the load run for a limited time, big storage systems are not required as it is done in conventional systems thus reducing the overall cost of the system compared to the conventional centralized storage systems. Furthermore, the voltages are well maintained within the safe limits without utilizing the fast-responding equipment such as super capacitors or huge battery banks at generation side that costs a lot. Being a developing country, the rural areas of Pakistan cannot afford sophisticated expensive solutions.

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