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European Journal of Advances in Engineering and Technology, 2022, 9(3):50-57

Review Article **ISSN: 2394 - 658X**

Unified Power Control and Energy Management between two Interlinked DC Microgrids

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ABSTRACT

Renewable integrated DC Microgrids (DCMGs) are gaining popularity by providing qualitative and quantitative energy to remote regions. Because of the stochastic behaviour of renewables, the reliability of autonomous DC microgrids (ADCMG) is dependent on battery capacity and size. Overcharging and discharging situations force the microgrid into an unstable state. Increasing storage capacity is not a cost-effective solution due to the higher maintenance and capital costs. When surplus power and deficit scenarios emerge in any of the DCMG, linking neighbour microgrids boosts virtual storing and discharging capacity. Control strategy is critical for controlling electricity inside and across microgrids. A power control and management system based on bus signalling is designed to govern sources, storages, and loads in order to accomplish effective coordination and energy management amongst microgrids. Because bus voltages are used to shift modes instead of separate communication lines, the proposed approach is simple and dependable. The proposed approach is tested using two controllers as conventional Proportional Integral (PI) and proposed Fuzzy Logic Controller (FLC) both are tested by using simulation/MATLAB tool.

Key words: Autonomous DC Microgrid, Bus signaling method, Power control and management scheme, Renewable sources, Real time simulation

INTRODUCTION

Isolated DC microgrids have piqued the interest of scholars in recent years [1] because to their advantages in addressing complexity control, synchronisation difficulties, harmonics, and reactive power [2]. Domestic customers, data centres, and communications systems in remote places in developing/undeveloped nations are serviced by local DC grids rather than conventional grids since utility connection is neither possible nor cost-effective [3]. In contrast to grid-connected DC microgrids [4], autonomous DC microgrids (ADCMGs) lack a utility to balance electricity between generation and consumption. Thus, excellent coordination and control are critical in ADCMGs to achieve optimal energy management and efficient resource and storage unit usage [5]. Control methods based on centralised controllers allow optimal functioning among multiple units by obtaining information from them and centrally managing the data [6]. However, system dependability suffers as a result of the system's reliance on the central controller and communication link. Droop control [7] is a simple decentralised control system that relies on local information but lacks optimal exploitation of microgrid resources. To address the aforementioned shortcomings, [8] presented a distributed control technique based on DC bus signalling method (DCBSM). However, it fails to take into account battery overcharging and draining. The state of charge (SoC) of the battery is incorporated in the primary level control based on DCBSM in [9]. Secondary level control is intended to alter bus voltage in accordance with the reference voltage. Because the battery alone manages the bus voltage, the system's dependability suffers. The use of DC bus voltage levels to decouple the operational zones in primary level control is proposed in [10]. Furthermore, secondary level coordination among multiple storage devices is accomplished through communication. Excess generation, on the other hand, is inefficiently controlled by utilising dump loads [11]. Proposes a multilevel energy management technique in which hybrid storage devices are used to suppress both low and high frequency components during power changes. If communication between control levels fails under overcharging or discharging situations, the hybrid storage devices are poorly controlled. Papers [12] offer several control strategies for managing the DC microgrid under variable generation and storage based on bus voltage deviation. Bus voltage is used in these studies to indicate the condition of DC microgrids. Both articles take into account the utility grid and allocate slack roles to different sources (i.e. utility grid side converter or storage converter) in each mode based on DC microgrid and utility grid circumstances. To optimise system performance, distinct control loops are used in each mode, which necessitates frequent switching between control loops, which creates switching transients and increases the stress on the control processor. Aside from that, [13] does not investigate surplus power over the battery charging rate and grid side converter rating. Although it is taken into account by [14], the variance of bus voltage in islanded mode is greater than 10% of the nominal value, affecting the sensitive loads attached. In [15], a power line signalling approach is presented to solve the problem of a restricted number of operating modes in DCBSM based on fixed voltage variation. It transmits the condition of batteries and other sources as discrete frequency signals overlaid on bus voltage. By collecting information from different frequency signals, various sources can change their functioning modes. However, this strategy is unsuitable for a growing number of storage systems (SS) and distributed energy resources (DER) since available carrier signal frequencies are restricted and vary depending on converter settings, making the suggested scheme difficult to implement. Above all, when a power surplus or deficit occurs in an ADCMG, an extra storage system is required, in addition to the charging and discharging capacity of the storage devices in the ADCMG. Increasing the SS will raise system costs owing to additional maintenance and startup costs. Furthermore, it adds complexity to control, which affects dependability indirectly owing to the need on quick processing and communication technologies across separate storage units. To minimise the need for extra storage, DC grid connectivity is being developed in the same way that traditional AC systems are (one region to another), which improves system resilience and makes more effective use of resources. Fig 1 depicts a typical configuration for linking ADCMGs. Each microgrid is comprised of distributed energy resources, storage systems, and a variety of loads. In this article, a power control and management strategy (PCMS) based on DCBSM is created for individual ADCMGs as well as between ADCMGs in the absence of a dedicated communication infrastructure. In PCMS, bus voltage information is used to control and manage sources, storages, and loads. Similarly, both bus voltages are utilised to initiate power exchange through the DABC between the ADCMGs. Furthermore, PCMS accommodates severe scenarios like as over and under loading conditions of individual ADCMGs, which are efficiently managed by performing load shedding and PV derating algorithms, respectively. PCMS is a simple and communication-free power control approach used within and across microgrids to provide optimal resource usage and management while also improving the dependability of ADCMGs.

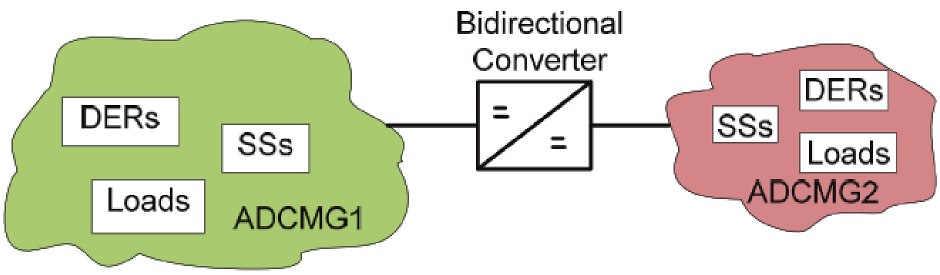

Fig. 1 Typical interconnection of two ADCMGs

SYSTEM STRUCTURE

The system considered in this research is depicted in Fig. 2, and it consists of two ADCMGs geographically separated from each other with significant line resistance between them. In order to simplify the analysis for the proposed PCMS between the ADCMGs, each ADCMG consists of one photovoltaic (PV) source and one battery, which are equal to groups of sources from renewable sources and storage device families, respectively.

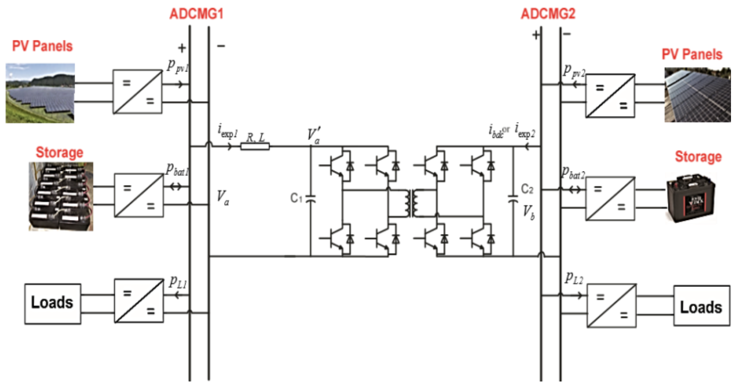

Fig. 2 System architecture for interconnection of two ADCMGs

As most of DC loads are of constant power loads (CPL) which are integrated through DC-DC converter. Hence, CPLs can able to maintain fixed power irrespective of variations in DC bus when its voltage oscillations lie within the sustainable range [15]. PV source is interfaced to DC bus through boost converter and bidirectional buck-boost DC-DC converter is utilized for connecting the battery storage. Interconnection of two ADCMGs is realized by considering DABC as interfacing unit which provides galvanic isolation and high power feeding capability in both directions along with large conversion ratios through high frequency transformer. Two full H-bridge converters are connected to either side of the transformer to produce the high frequency AC from DC. Besides, this topology recognized as DABC and widely employed in transferring the power from low to high voltage DC [12].

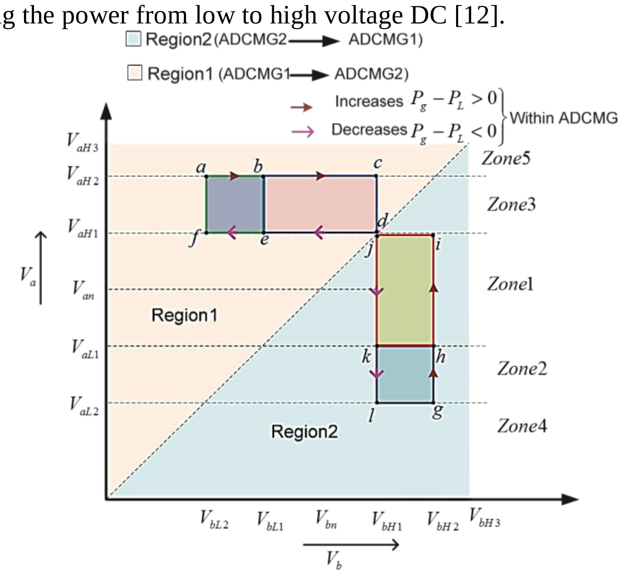

Fig. 3 Proposed PCMS between two ADCMGs

Zone 1 (Balanced power mode): Because the power provided by the PV source (pPV1) is about equal to the demand (pL1) in the ADCMG1, the battery remains in an idle condition. In this mode, small variations in load and source will not activate the storage unit since established voltage limits can withstand these fluctuations. Because there is no constant source to regulate the bus voltage in this zone, its voltage might vary between the limits VaH1 and VaL1, which are considered the borders of this mode for ADCMG1. Similarly, VbH1 and VbL1 are ADCMG2 borders. Neither of the ADCMGs in this zone shares power with any other ADCMG. The status of several units in ADCMG1 is provided by

$$p_{PV1} \cong p_{L1}; \quad p_{bat1} = 0; \ V_{aL1} < V_a < V_{aH1} \qquad (1)$$

Zone-2 (Battery discharge mode): Because PV output is insufficient to meet demand, a constant divergence in bus voltage occurs (Va). When Va falls below a certain threshold value (VaL1), storage enters discharging mode from idle in order to bridge the supply-demand gap. By remaining in bus regulating mode, the battery maintains the bus voltage at the same threshold (VaL1). If surplus power from ADCMG2 is accessible (i.e. operating point h in Fig. 3), ADCMG1 is ready to absorb it, but reverse power transfer is not feasible. The control loop takes into account the battery's extreme circumstances. The conditions of ADCMG1 are represented by the equation

$$p_{PV1} + p_{bat1} = p_{L1}; \qquad V_a = V_{aL1} \qquad (2)$$

Zone-3 (Battery charge mode): If the PV source produces more power than needed, this mode enters the picture, where voltage Va increases constantly owing to excess power and stops at the threshold limit (VaH1) by moving the battery into charging mode. The battery may charge until the cutoff limit is reached. When Vb is at VbH2 and battery1 in ADCMG1 is not fully charged or the maximum charging rate is not achieved of ADCMG1, ADCMG1 cannot feed power to ADCMG2, but it can absorb power from it.

$$p_{PV1} > p_{L1}; \quad p_{bat1} = -(p_{PV1} - p_{L1}); \quad V_a = V_{aH1} \tag{3}$$

Zone-4 (Power deficit mode): This mode is an extension of zone-2 and activates when the load exceeds the battery's discharge rate. The battery operates at its maximum discharging current limit in this mode. This zone has two sub cases, the first of which deals with power import from ADCMG2, and the second with no power import from ADCMG2.

$$V_a = \begin{cases} V_{aL1} & : if\ p_{PV1} + p_{bat1} + p_{imp1} = p_{L1} \\ V_{aL1} < V_a < V_{aH1} : if & p_{PV1} + p_{imp1} \cong p_{L1} \\ V_{aH1} & : if\ p_{PV1} + p_{imp1} > p_{L1}, p_{bat1} = -(p_{PV1} + p_{imp1} - p_{L1}) \end{cases} \tag{4}$$

Zone-5 (Excess power mode): This zone is further divided into two sub cases, one dealing with exporting surplus power from ADCMG1 and the other not.

$$V_a = \begin{cases} V_{aH2} & : if\ p_{\exp1} > 0 \\ V_{aH3} & : if\ p_{\exp1} = 0\ \&\ V_{PV1ref} = V_{aH3} \end{cases} \tag{5}$$

CONTROL LOOPS

Converter control is critical in executing the proposed PCMS for switching the source converters between different modes based on predetermined triggering criteria. Because the outer loop is saturated and does not supply any reference to the inner loop until and unless the stated threshold voltage is reached by the DC grid, this mode will not be active until and unless the defined threshold voltage is reached by the DC grid. The control structure for battery1 and PV source1 inside ADCMG1 is elaborated, and the same control structure is used in ADCMG2 for battery2 and PV source2. The power flow regulation of IBDC between two DC grids is thoroughly detailed.

PV control loop

Except in zone 5, the PV source remains at MPP regardless of load or power import/export, ensuring that the maximum renewable power is collected and utilised efficiently.The PV control loop of ADCMG1 is depicted in Fig. 4, and the PV source in ADCMG2 is depicted in the same way. The PV source may be operated in two modes: MPP mode and bus voltage regulation mode. The first is made up of two loops, the outer of which is used to track MPP voltage (VMPP) using the perturb and observe (P&O) approach and gives a voltage reference as input to the inner loop. The inner loop operates at a quicker rate to monitor the specified reference through the PI controller and produces the duty cycle (1pv) as its output. The second mode just includessimply altering the duty cycle on the PI controller by sending the duty cycle to the PWM comparator, both modes provide the needed pulses for switches inside the converter. Observation is used to choose switch between two modes. the voltage on the bus If the Va rises over the maximum limit If VaH2 is present, PV will enter the bus regulation mode; otherwise, PV will not enter the bus regulation mode. Continues to operate in MPP mode. Despite the fact that battery1 is completely charged, However, because of extra power, PV is not forced into regulation mode. A transition from ADCMG1 to ADCMG2 may occur for the effective use of renewable energy, which raises System dependability

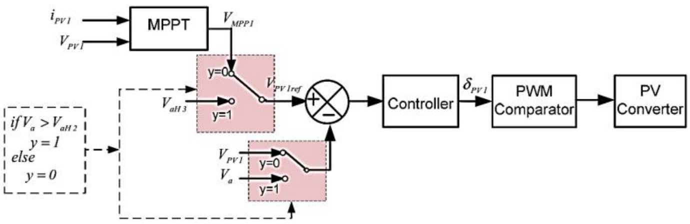

Fig. 4 Control loop of PV source in ADCMG1

Control loops for batteries

Based on their cut in thresholds, batteries operate in either charging or discharging modes. Fig 5 depicts the ADCMG1 battery control loop. Each mode has two loops, with the inner loop shared by both modes. No mode will be active until the bus voltage exceeds its preset threshold value owing to controller saturation. The outer voltage loop primarily tracks the bus voltage reference and generates the current reference as an output, which is sent to the inner loop for effective reference tracking. In discharging mode, the top outer loop provides positive reference current (Ibtrd1) by controlling bus voltage (Va) at VaL1 when load dominates, which is sent to the discharging rate limiter and then compared to its cut off.

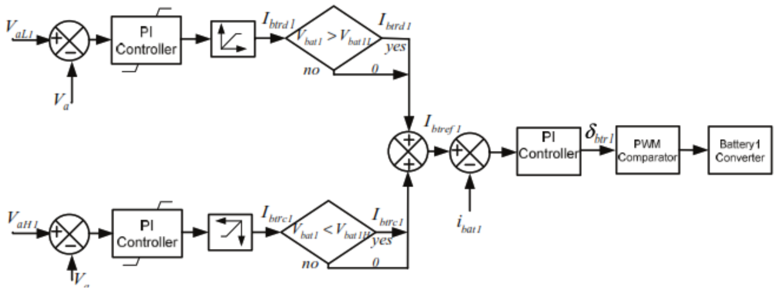

Fig. 5 Control loop of battery in ADCMG1

Bidirectional power control between ADCMGs

DABC is used as a bidirectional DC-DC converter (BDC) for power transmission between ADCMGs. It mostly use the traditional phase shift approach [15]. Power is transferred from ADCMG1 to ADCMG2 or from ADCMG2 to ADCMG1. Fig 6 depicts BDC control. It is made up of two loops, the outer voltage loop and the inner current loop. When one of the two ADCMGs has excess power that the other grid can absorb, the BDC enters an active mode. Power transfer from ADCMG2 to ADCMG1 is considered a positive convention, whereas opposite action is considered a negative convention.

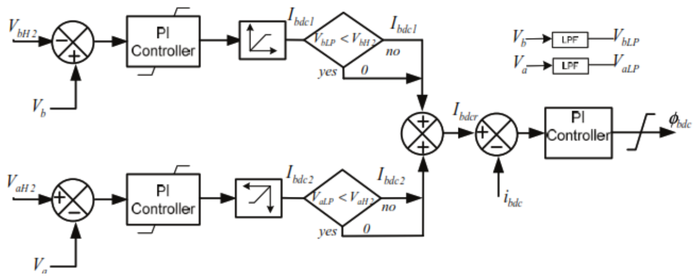

Fig. 6 Control of BDC between two ADCMGs

Load control

In this work, a constant power load is created by feeding a resistive load via a buck converter. The control system for buck converters is similar to that of conventional control schemes. Load shedding is carried out based on DC bus voltage and battery state, as seen in Fig. 7. If the battery voltage falls below the cutoff value VbatL2 (corresponding to SoC=30%), load shedding is activated to protect the battery's ability to adequately supply the important loads. Similarly, if the bus voltage falls below the lower threshold (VaL2), load shedding is started since the power shortfall exceeds the battery's discharge rate. If both occur at the same time in the worst-case scenario, load shedding is triggered.

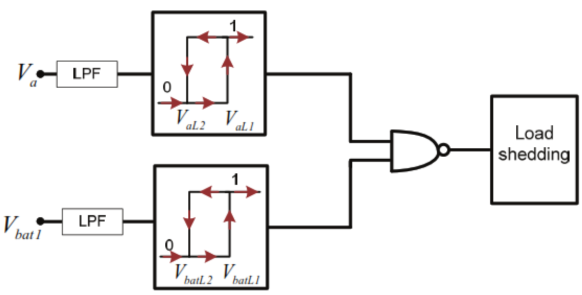

Fig. 7 Load shedding control

SIMULATION RESULTS

To validate the designed PCMS, simulation of the system depicted in Fig. 2 is performed using a real-time digital simulator (RTDS) platform. The system is built in the RSCAD/RTDS environment. Table I details the specifications of system components such as PV, battery, and load in both ADCMGs. To demonstrate the usefulness of PCMS, two practical DC grid voltage values are used. Loads are characterised as fixed or variable based on their presence throughout a specific time period.

Table -1 Simulation Parameters

Components	**Parameters**	**ADCMG1**	**ADCMG2**
PV Capacity	Maximum power@1000W/m2	4.5 kW	750 W
Battery	Capacity	200 AH	100 AH
	Nominal voltage	96 V	24 V
Nominal grid voltage	Rated voltage	380 V	48 V
Voltage Thresholds	VxH3	410	54 V
	VxH2	400	52 V
	VxH1	390	50 V
	VxL1	370	46 V
	VxL2	360	44 V
DC load	Fixed Load	1 kW	200 W
	Variable Load	2 kW	300 W
Line parameters	Resistance(R)	0.15 Ω	
	Inductance (L)	0.24mH	

Individual DC microgrids

Figure 8 depicts the various working zones of ADCMG1. To collect all zones, even extreme situations, into a single window, the battery terminal voltage is kept slightly over the lower cut off limit. Cutoff limits for each zone are chosen with a difference of 10V [14], and bus voltage variation for all zones is less than 5% of the bus nominal voltage. The figure shows that produced power is equal to load demand from 0 to t1, which represents the operating zone-1, during which bus voltage is allowed to vary across borders. At time t1, an increase in PV power (pPV1) produces an excess of power relative to local demand (pL1), which prompts the battery to enter charging mode from the idle state in the previous scenario and begin regulating the voltage.

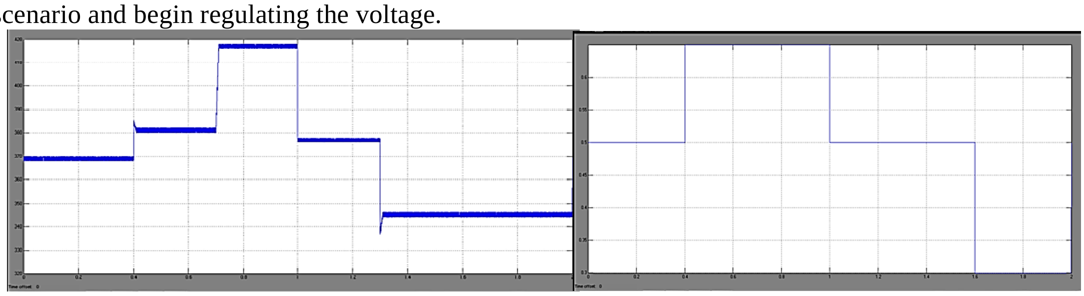

Fig. 8(a) Bus voltage of ADCMG1 (b) Irradiation of ADCMG1

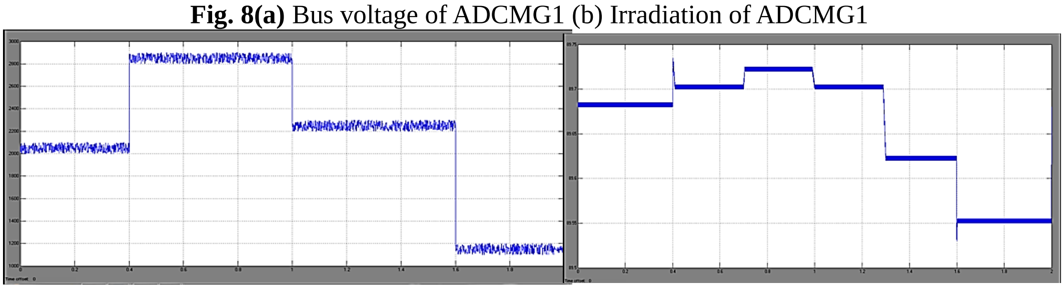

Fig. 8 (a) PV output power of ADCMG1 (d) Battery terminal voltage of ADCMG1

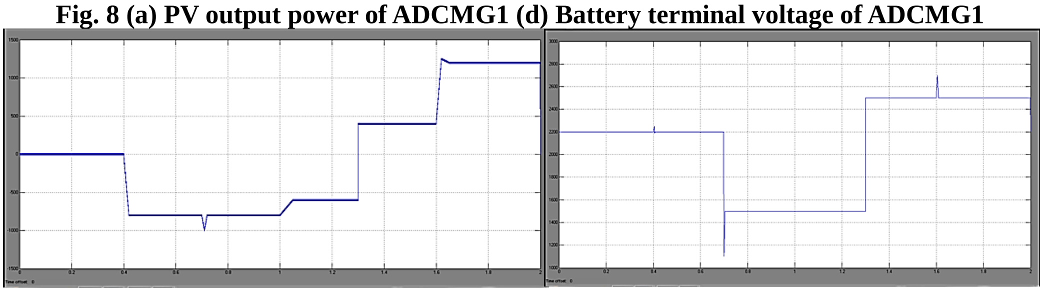

Fig. 8(e) Battery output power of ADCMG1 (f)Load power

Inter DC grid power flow

Simulation of inter DC grid power flow using developed PCMS is shown in Fig. 9. From a to f, ADCMG1 is operated in zone-3 where the generation dominates the power demand and battery is charging with surplus power as shown in Fig. 9(e). Simultaneously ADCMG2 is in zone-2 with predominant load. Further increase in load occurs at t7 and clamp the bus voltageVb at VbL1 till t8 . Sudden rise in PV power (pPV1) insideADCMG1 at t8 causes the battery to charge at its saturation current limit due to surplus power which pushes the bus voltage (Va) to increase further. Once Va reaches VaH2, then BDC control checks the status of other grid (i.e.ADCMG2). As Vb≤ VbH1, then BDC is allowed to deliver the power from ADCMG1 to ADCMG2 by controlling the BDC output current as shown in Fig. 9(c)-(d). Though power is transferred from ADCMG1.

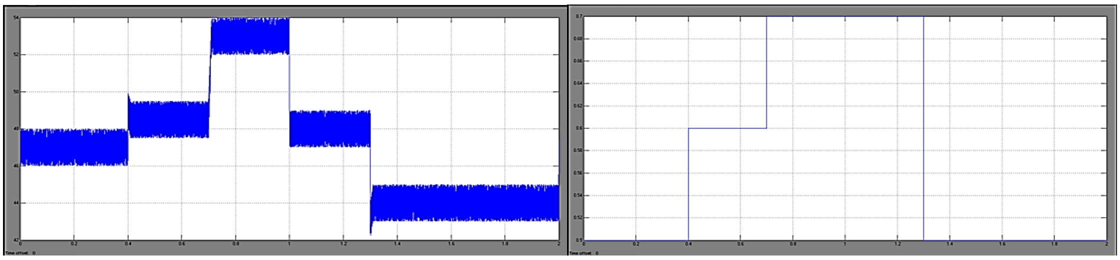

Fig. 9(a) Bus voltage of ADCMG2 (b) Irradiation of ADCMG2

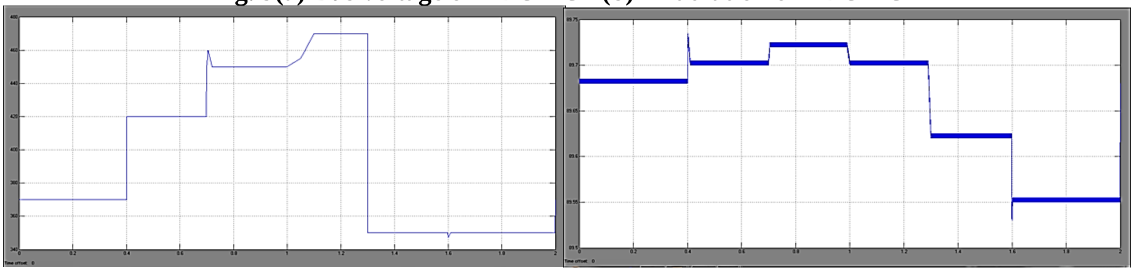

Fig. 9 (a) PV output power of ADCMG2 (d) Battery terminal voltage of ADCMG2

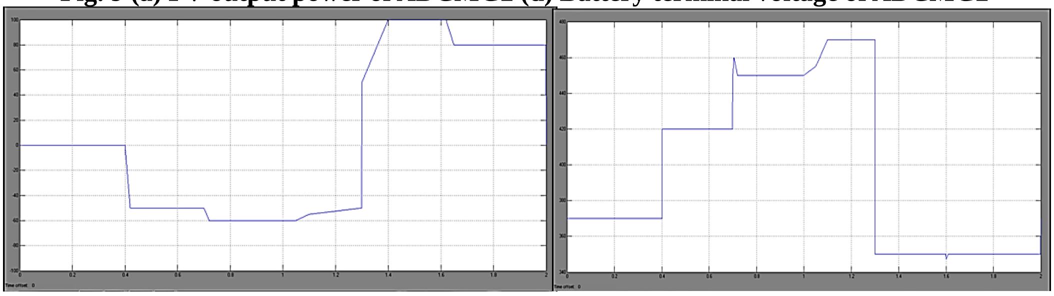

Fig. 9 (e) Battery output power of ADCMG2 (f) Load power of ADCMG2

CONCLUSION

In the case of ADCMGs, a PCMS based on bus signalling approach is created to promote system dependability and efficient resource use. In simulation, the performance of the devised method is evaluated using two practical DC grid voltages (380V and 48V). PCMS is investigated in both typical and extreme settings, including over and under loading conditions of ADCMGs, as well as overcharging and discharging of the battery. According to the results of the preceding study, the suggested PCMS is stable, efficient, and effective in accomplishing communication independent control even when dynamic power changes occur during the power exchange. This assertion is further supported by experimental findings acquired using a prototype model created in the laboratory with a lower voltage of ADCMG1. The proposed solution enables isolation while simultaneously improving system dependability. The system's application potential is suited to low and medium voltage customers such as household consumers, data centres, communications systems, and so on in remote places where utility connections are not existent or practicable.

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