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Research Article

Power-Sharing Analysis of Hybrid Microgrid Using Iterative Learning Controller (ILC) considering Source and Load Variation

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In this study, a novel iterative learning controller is proposed to maintain power balance in hybrid microgrid considering source and load variation. A hybrid microgrid comprising of solar, battery, utility grid, and AC and DC loads are developed with ac and dc bus in MATLAB Simulink environment. The primary or local level control is implemented for solar and battery for maintaining stable dc bus voltage. The secondary or system level control is implemented by controlling the interlinking converter placed between ac and dc bus to supply stable voltage along with the smooth grid synchronization and ensuring the proper real power sharing between dc/ac buses. The simulation studies reveal that the proposed iterative controller has efficient and effective control over the voltage and power in hybrid microgrid under various modes of operation such as autonomous and grid connected modes.

1. Introduction

The traditional strategies for generation of electrical energy can cause great negative impacts on the natural fuel sources and have more wastages of energy during power generation and transmission. The distributed energy resources (DER), energy storage systems (ESS), and loads form a microgrid (MG) that acts as single controllable unit from the grid point of view [1]. Microgrid has reduced power loss and improved power quality and reliability. Due to the sporadic environment of renewable energy sources, MG must be linked to the conventional grid for continuous and reliable power supply. When the MGs are operated in the grid connected mode, it facilitates the bidirectional power transfer between the microgrid components and the utility grid (UG).

The most preferable microgrid structure is AC microgrid which could be easily coupled with the UG through point of common coupling (PCC) [2]. However, DC microgrids are developed currently due to solar power generation compatibility, energy storage facility, and increase in DC loads such as electric vehicles, LED lighting, and data centers [3]. Because increase in DC power sources and majority of loads in the utility grid are AC loads, hybrid AC/DC microgrids are emerging recently. To decrease the power conversion phases, to improve the efficiency, and to provide a reliable and quality power supply, AC subgrids and DC subgrids have been developed with their DERs and loads; this in turn forms a hybrid microgrid (HMG) [4].

Both subgrids of AC and DC in an HMG are connected together through an interlinking converter (IC) which enables the power flow in both directions between the grids [5]. Generally, the control techniques for IC control are responsible to sustain bus voltages in HMG. The droop control of ICs for power disbursement among AC and DC subgrids ends up with frequency deviation and low voltage quality which leads to system instability. Also, achieving both accurate (optimal) power sharing and voltage control is very difficult with the droop control [6].

Most of the literature discussed the energy management strategies used in hybrid microgrid controlled by the system operator. Rather than this centralized system, the authors [7] proposed a management system having distributed nature for finding day-ahead schedules using the information obtained from the energy management solution. The mixed integer quadratic programming has been formulated with the constraints of distributed energy sources, storage system, system operation, and converter operation constraints. The results proved that the proposed algorithm has effective optimal energy management for hybrid microgrid. An optimal energy strategy has been proposed with display in [8] for the grid connected and standalone microgrid having wind, solar, fuel cell, diesel generator, and microturbine as sources and battery energy storage systems. Using mixed integer linear programming with multiobjective solution of demand response program, with these techniques and energy management strategy, the carbon dioxide emission has been reduced almost fifty percentage.

An economic and environmental analysis of a grid tied microgrid is carried out in [9] for the cost saving and reduced CO_2 emission. The battery life and daily operation cost is considered in this work which yields almost 99 percent saving in cost and giving income also with the application of hybrid FMINCON and GA algorithms. Various topology of hybrid energy storage system (HESS) is proposed in [10] having passive, semiactive, and active topologies. The analysis of various systems is carried out taking the parameters of cost, flexibility, efficiency, complexity, and controllability, and the results show that the system with power electronic interference has better performance, and it is sensitive to state of charge level.

The HMG operated in both grid connected and autonomous mode and its transition is controlled by the IC located between AC and DC buses. Even though many controllers have been available for the microgrid application, iterative learning control (ILC) [11] is considered and implemented in this study because of its repetitive nature. The concept of ILC started from robotics engineering for its repetitive movements. ILC has been accepted to be an effective method of the control method to enhance the dynamic response for a set up with repetitive act [12]. In this study, an HMG is modelled in MATLAB/Simulink simulation environment with solar and battery along DC bus side; AC loads and utility grid are connected to AC bus. AC and DC subgrids are interconnected through IC. For efficient power sharing and voltage control, the iterative learning controller with the forgetting factor is implemented for control of IC. The developed microgrid is controlled by IC with the aid of proposed ILC, which utilizes the DC bus voltage as controller input.

The uniqueness of this research work is listed as

(i) Implementation of novel ILC to enrich the output of the controller used for interlinking converter operation for optimizing the power-sharing method, stabilizing voltage and frequency

(ii) Simulation analysis of the hybrid microgrid under various scenarios and its realization

2. Structure of Hybrid Microgrid System and Operation

The presented HMG shown in Figure 1 comprises of separate DC and AC buses which are interconnected to each other through IC. The modelling of solar, battery, and the entire microgrid set up has been referred from [13], and the specification is given in Table 1. Furthermore, AC bus with local loads is linked with the utility grid through the transformer at PCC. Solar photovoltaic (PV) panel is treated as the main source for HMG and the battery is served to be the storage and back up device to satisfy the time-varying loads. The boost converter for DC operation is used to get the maximum power from the PV with maximum power point tracking (MPPT). The function of battery in HMG is used to store the excess energy from the PV source and deliver the power to loads whenever the voltage production from the PV system is less.

Typically, the PV source has variable power output due to variations in its input solar irradiation. Still, the voltage level of the PV source must be the same, irrespective of its input variations. In order to maintain a constant voltage at DC bus, the decentralized fuzzy logic controller is employed for the solar converter. The dc bus voltage is being converted to AC voltage using IC. The IC in an HMG is playing the role of rectifier and an inverter reliant on the power flow direction at every instant. The control and co-ordination of hybrid microgrid with various control approaches are highlighted in [14], and the ICs are deployed as the grid-side converter for the transfer of renewable energy power to the AC grid. Due to the intermittent power output from the renewables, it is necessary to take severe steps to avoid the opposing effects of the renewable sources. Hence, HMG control is more significant to meet out the power balance and the voltage stability by ensuring the good performance as well.

3. Materials and Methods

A method of the repetitive controller called iterative learning controller (ILC) is used for the control of IC in both modes of operation for efficient power management and voltage control of HMG. The concept of ILC and its implementation to meet out the control objectives are referred from [15]. The proposed HMG shown in Figure 1 has been modelled in MATLAB/Simulink. In this research work, the solar PV panel is assumed to be the base source to meet the loads since it is the best clean and environment friendly energy. The various modes of operation, duration of PV source, and grid availability are highlighted in Table 2.

The solar cell control logic and battery control algorithm has been implemented to maintain stable dc voltage at the dc

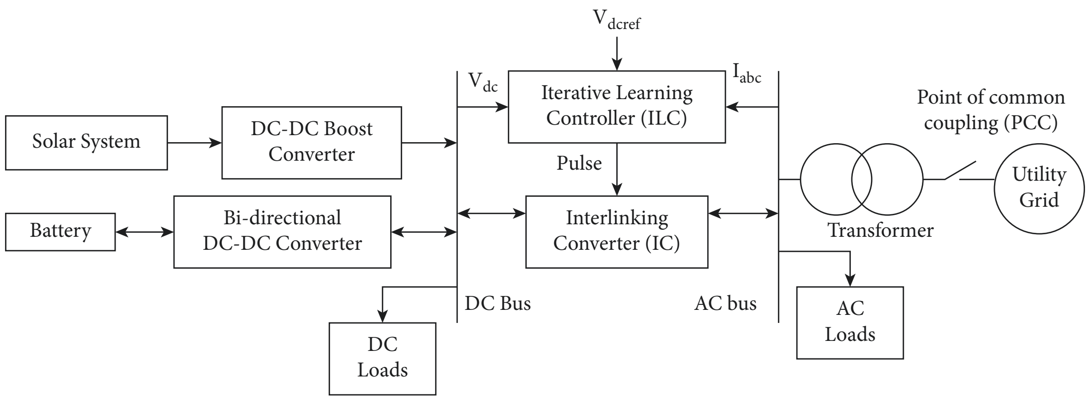

Figure 1: Block diagram of the proposed hybrid microgrid.

Table 1: Specification of HMG setup.

Sl. no.	Parameters	Values
1	Solar power rating	1 kW, 135 V operating voltage
2	DC-DC boost converter	1 kW
3	Battery rating	8 nos of 12 V, 120 Ah
4	Bidirectional converter	1 kW, SKM100GB12T-IGBT
5	DC link capacitor	400 μF
6	DC bus voltage	200 V
7	Transformer	3Φ, 6 A, 415/(0–470 V)

Table 2: Various scenarios under autonomous and grid connected mode of operation for HMG.

Mode of operation	Cases	Description	Interval in sec	Solar panel	Battery
Autonomous mode	Scenario-I (SC-I)	Abundant solar energy + normal loading	0.0–5.0	MPPT	Charging
	Scenario-II (SC-II)	Abundant solar energy + heavy loading	5.0–10.0	MPPT	Discharging
	Scenario-III (SC-III)	Abundant solar energy + light loading	10.0–15.0	Constant power	Charging/idle
	Scenario-IV (SC-IV)	Absence of sunlight + normal loading	15.0–20.0	No power	Discharging
Transition mode	Scenario-V (SC-V)	Mode change	@25s	Mode change from autonomous to grid connected mode	
Grid connected mode	Scenario-VI (SC-VI)	Power import + normal loading	20.0–25.0	No power	Discharging/ idle
	Scenario-VII (SC-VII)	Power export + light loading	25.0–30.0	MPPT	Charging/idle

bus irrespective of the variation in the solar input and load variation. The control diagrams of solar and battery are explained in Figures 2 and 3, respectively.

In the figures, I_{pv} and V_{PV} are the solar output current (A) and voltage (V), respectively, V_{dc} and V_{batt} are the dc bus voltage and battery output voltage, respectively, and I_L and I_o are current (A) from the battery and dc-dc converter currents, respectively. Instead of real power P control, *Vdc* can be employed in the outer control loop particularly for solar applications. The fundamental concept behind this theory is that the capacitor voltage depends on the energy balance between the power received by the VSI and the power delivered by it.

If these two are equal, then the dc-link voltage will remain constant. If power received by VSI is greater than the power delivered by it, then the extra energy will be put into the capacitance which in turn will elevate its voltage. On the contrary, if the power delivered by VSI is greater than the power received, then the additional power is supplied by the capacitor results in the reduction of its voltage. Thus, by monitoring the dc-link voltage, it is possible to deliver a required amount of active power.

The entire simulation is carried out for 30 sec under these operating conditions; the power distribution among the source, battery, and loads is shown in Figure 4.

3.1. Autonomous Mode. In this condition, HMG is isolated from the main grid and operates autonomously. The solar PV panel and energy storage device in the microgrid are alone delivering the power to the loads [16]. To verify the performance of HMG with the proposed ILC controller, four different scenarios are analyzed under solar isolation varying and load fluctuations [17].

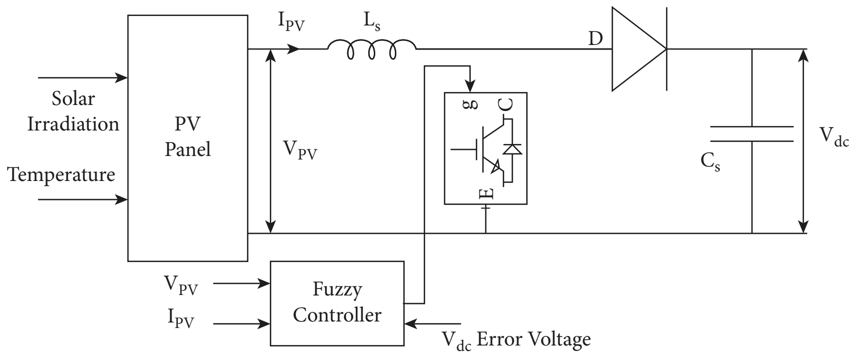

Figure 2: Block diagram of the DC-DC converter for solar cell.

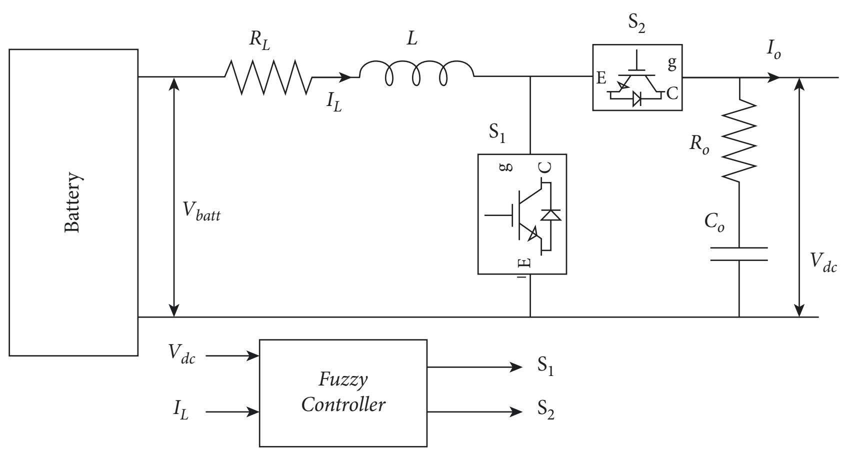

Figure 3: Block diagram of control circuit of battery.

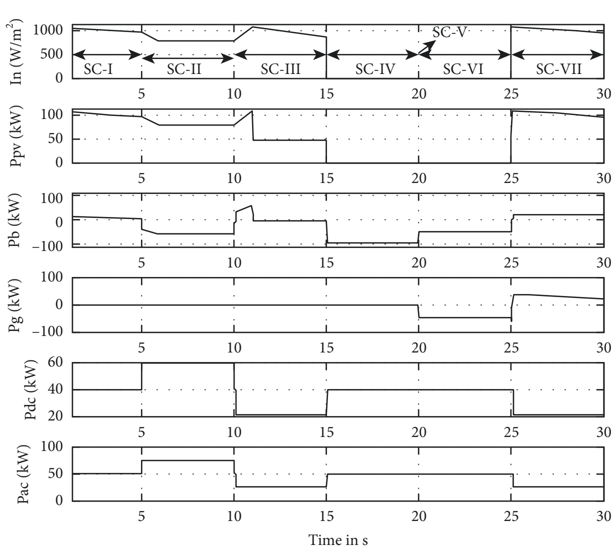

Figure 4: Power distribution among various sources and loads for HMG.

3.1.1. Scenario I: Solar Supplies Power to Loads and Charging Battery. In this scenario, an abundant amount of sunlight is falling on the PV panel, and fixed nominal loads are present at DC and AC subgrids. Under this condition, the DC-DC enhancement converter is operating in MPPT mode to extract the peak power from the solar panel and deliver the maximum power to loads [18]. The surplus power from the solar is charging the battery.

3.1.2. Scenario II: Solar Power Reduces and Battery Discharges for an Increase in Loads. In this scenario, an abundant amount of sunlight is falling on the PV panel, but loads are slightly increased above the nominal ratings. Under this condition, the converter still operates in MPPT mode to get the highest power from the PV panel and delivers a position of power to the loads [19]. To maintain a proper power balance between the sources and loads, the excess power demand by the loads is taken from the energy storage device by discharging it [20].

3.1.3. Scenario III: Solar in Constant Power Mode and Battery Is in Idle Condition. In this scenario, an abundant amount of sunlight is falling on the PV panel, but loads are slightly decreased below the nominal ratings. Under this condition, total load demand can be lesser than the power output from the PV panel when it operates in the MPPT mode [21]. Thus, the DC-DC boost converter is operating in the constant power mode to maintain the proper power distribution among the components to meet the balance. Under this condition, the battery is being charged until SOC upper limit and it becomes idle [22].

3.1.4. Scenario IV: No Solar Power and Battery Discharges for Constant Load. In this scenario, an absence of sunlight or deficit amount of solar energy is falling on the PV panel to generate sufficient power, and nominal loads are connected at the subgrids. Under this condition, there is no power available from the PV panel; hence, the battery is being discharged to satisfy the load demands until it reaches the SOC lower limit [23].

During transition mode from autonomous to grid connection, the breaker at PCC is closed, and the HMG is connected to the utility grid. It is observed that the dc bus voltage has 8.34 percentage deviation for 0.015 s and settles to the desired value [24]. This indicates that the proposed controller operates efficiently and has an ability to maintain the voltage and frequency constant.

3.2. Grid Connected Mode. Once the HMG is coupled to the utility main grid, the HMG functions in either power export mode or power import mode are subject to the presence of solar energy from the sun. These two modes of operation under grid connected condition are discussed as follows.

3.2.1. Scenario V: No Solar Power and Grid Supplies Power to Loads and Charges the Battery. This scenario is considered as HMG power import mode. In absence of sunlight, no power can be extracted from the PV panel. Hence, the energy storage device in the HMG starts to discharge and deliver the power to loads until SOC limits, and it becomes idle [25]. Meanwhile, HMG gets the essential power from the grid to maintain the power balance.

3.2.2. Scenario VI: Solar Power Exports to Grid and Battery Is in Fully Charged. In this scenario, an abundant amount of sunlight is falling on the PV panel, and loads are slightly decreased below the nominal ratings [26]. Under this condition, the DC-DC boost converter operates in the MPPT mode and extracts utmost power from the PV panel. The PV power satisfies the load demands and the residual extra power is utilized for charging the battery. When the battery reaches the SOC upper limit, the HMG starts to export this extra power to the main grid.

4. Conclusion

A hybrid microgrid comprising of solar, battery, and loads has been considered for the simulation analysis. Individual decentralized fuzzy-based controllers have been implemented for the solar and battery to provide fixed dc voltage irrespective of its input variation. Novel iterative learning controller has been implemented for the control of the interlinking converter to ensure the constant bus voltages and frequency under various modes and scenarios for varying generation and loading conditions. The controller is also responsible for the power management among the source and the loads. The simulation results reveal that the power sharing among the source and loads under variable conditions is enhanced with ILC. In future, the hardware implementation of the proposed hybrid microgrid will be carried out for power export and import operation. In the future work, the voltage and frequency stabilization and current measurement with additional loads will be considered. The optimization algorithms for the parameter improvement will also be implemented in the research work in future.

Data Availability

The data used to support the findings of this study are included within the article. For further data or information, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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