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Research Paper

A ROBUST ELECTRIC VEHICLE-ASSISTED CONTROL STRATEGY FOR REACTIVE POWER OPTIMIZATION AND INTERLINKING CONVERTER CAPACITY REDUCTION IN HYBRID AC/DC MICROGRIDS

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ABSTRACT

Hybrid AC/DC microgrids have emerged as an effective solution for integrating renewable energy resources, energy storage systems, and electric vehicles (EVs) while improving overall energy efficiency and operational flexibility. However, conventional hybrid microgrids rely heavily on interlinking converters (ILCs) to exchange active and reactive power between AC and DC subgrids, resulting in increased converter capacity, higher investment cost, and additional power losses. Moreover, inadequate reactive power management can lead to voltage instability, poor power quality, and inefficient utilization of distributed energy resources. This paper presents an improved control strategy that utilizes the reactive power capability of electric vehicles to support the AC subgrid while simultaneously reducing the power handling requirement of the interlinking converter. The proposed strategy enables coordinated control of EV charging stations, renewable energy sources, and the interlinking converter to achieve optimal power sharing, enhanced voltage regulation, and improved system stability. By allowing EVs to actively participate in reactive power compensation, the required converter rating is significantly reduced without affecting system performance. Simulation results demonstrate improved voltage profiles, reduced converter loading, lower power losses, enhanced power quality, and better dynamic response under varying load and renewable generation conditions. The proposed approach provides an economical, reliable, and scalable solution for future smart hybrid AC/DC microgrids with high penetration of renewable energy and electric vehicles.

INTRODUCTION

The increasing penetration of renewable energy resources, such as photovoltaic (PV) systems and wind energy conversion systems, has accelerated the development of hybrid AC/DC microgrids as an efficient and flexible power distribution architecture. Hybrid microgrids combine the advantages of both AC and DC networks, enabling seamless integration of renewable energy sources, battery energy storage systems, electric vehicles (EVs), and conventional loads while improving overall system efficiency. The interlinking converter (ILC) serves as the key interface between the AC and DC subgrids by facilitating bidirectional power exchange and maintaining system stability. However, as renewable penetration and load demand continue to increase, the interlinking converter often requires a larger power rating, leading to higher installation costs, increased converter losses, and reduced overall system efficiency.

Electric vehicles are rapidly becoming an integral component of modern smart grids due to their growing population and advanced bidirectional charging capabilities. Beyond serving as transportation devices, EVs equipped with power electronic converters can participate in grid support functions through Vehicle-to-Grid (V2G) technology. These capabilities enable EVs to exchange active power, provide reactive power compensation, support voltage regulation, and enhance grid stability. Despite these advantages, many existing hybrid microgrid control strategies primarily utilize EVs for active power management while overlooking their potential contribution to reactive power support.

Conventional reactive power compensation methods depend mainly on static compensators, dedicated reactive power devices, or oversized interlinking converters, increasing both capital investment and operational complexity. Furthermore, centralized control approaches often fail to respond effectively to rapid variations in renewable generation, fluctuating loads, and dynamic EV charging conditions. Consequently, maintaining voltage stability, reducing converter stress, and improving power quality remain major challenges in hybrid AC/DC microgrids.

To overcome these limitations, this paper proposes an improved coordinated control strategy that actively incorporates electric vehicles into reactive power management. The proposed method enables EV charging stations to provide reactive power support to the AC subgrid while reducing the reactive power burden on the interlinking converter. This coordinated operation decreases the required converter capacity, minimizes power losses, enhances voltage regulation, and improves overall microgrid stability. The control strategy also ensures balanced power flow between AC and DC subgrids under varying operating conditions while maintaining reliable EV charging and discharging operations.

Simulation studies validate the effectiveness of the proposed approach under different renewable generation levels, load variations, and EV participation scenarios. The results demonstrate significant improvements in voltage stability, reactive power sharing, converter utilization, power quality, and overall system efficiency compared with conventional control methods. Therefore, the proposed strategy offers a practical, cost-effective, and scalable solution for future intelligent hybrid AC/DC microgrids with high renewable energy penetration and widespread adoption of electric vehicles.

LITERATURE REVIEW

Hybrid AC/DC microgrids have emerged as an effective solution for integrating renewable energy resources, energy storage systems, and electric vehicles (EVs) while improving system reliability and operational flexibility. The interlinking converter (IC), which connects the AC and DC subgrids, plays a crucial role in balancing power flow, maintaining voltage and frequency stability, and enhancing power quality. Traditional control strategies primarily focus on active power sharing through droop control; however, they often require oversized interlinking converters to handle both active and reactive power demands, resulting in increased system cost and reduced efficiency.

Recent studies have introduced hierarchical and model-based control methods to improve the performance of hybrid microgrids. These approaches employ coordinated droop control and advanced converter management to achieve stable bidirectional power transfer between AC and DC subgrids while maintaining DC bus voltage and AC frequency within acceptable limits. Although these methods improve power sharing and system stability, they provide limited utilization of distributed energy resources, particularly electric vehicles, for reactive power support.

The integration of electric vehicles through Vehicle-to-Grid (V2G) technology has opened new opportunities for enhancing microgrid operation. EV batteries can function as distributed energy storage systems capable of charging and discharging according to grid requirements. Several researchers have demonstrated that coordinated EV participation improves load balancing, voltage regulation, and renewable energy utilization while reducing dependence on conventional energy sources. However, many existing approaches mainly utilize EVs for active power management and do not fully exploit their capability for reactive power compensation.

To overcome these limitations, the proposed research introduces an improved hierarchical control strategy based on DC voltage droop control for the interlinking converter combined with a modified droop control algorithm for EV bidirectional converters. The strategy enables EVs to actively participate in reactive power management by regulating battery charging and discharging according to DC bus voltage variations. Consequently, the reactive power demand of the AC subgrid is shared between the interlinking converter and EVs, reducing the required rated capacity of the converter while maintaining effective voltage regulation and bidirectional power flow. Simulation results demonstrate enhanced reactive power compensation, improved power quality, increased converter utilization, and reduced converter sizing under different operating conditions.

Overall, this work represents a significant advancement in hybrid AC/DC microgrid control by integrating electric vehicles into reactive power management. The proposed strategy enhances system efficiency, improves renewable energy integration, minimizes converter overrating, and supports the development of resilient and intelligent smart grid infrastructures capable of accommodating increasing levels of distributed energy resources

PROBLEM STATEMENT

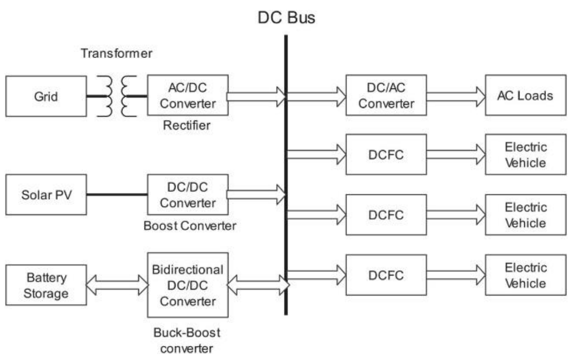
Hybrid AC/DC microgrids have emerged as an effective solution for integrating renewable energy sources, energy storage systems, and electric vehicles (EVs). However, conventional hybrid microgrids rely heavily on interlinking converters (ILCs) to transfer active and reactive power between AC and DC subgrids. During periods of fluctuating renewable generation and varying load demands, these converters experience increased loading, resulting in higher power losses, oversized converter ratings, reduced efficiency, and increased operational costs. Furthermore, inadequate reactive power management in the AC subgrid can lead to voltage instability, poor power factor, and degraded power quality. Although electric vehicles possess bidirectional charging capabilities that enable Vehicle-to-Grid (V2G) operation, existing control strategies often underutilize EVs for reactive power support and converter load sharing. Therefore, there is a need for an improved control strategy that enables electric vehicles to actively participate in reactive power management, minimizes the burden on interlinking converters, enhances voltage regulation, improves overall system efficiency, and ensures reliable operation of hybrid AC/DC microgrids.

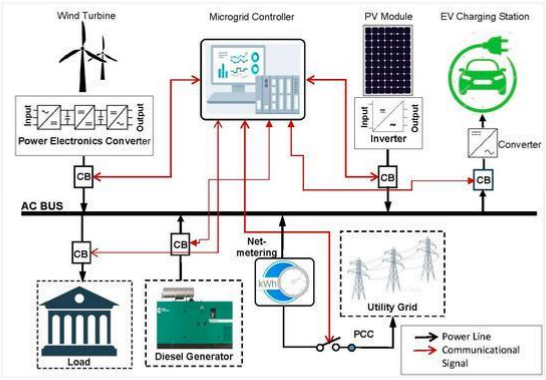
OBJECTIVES

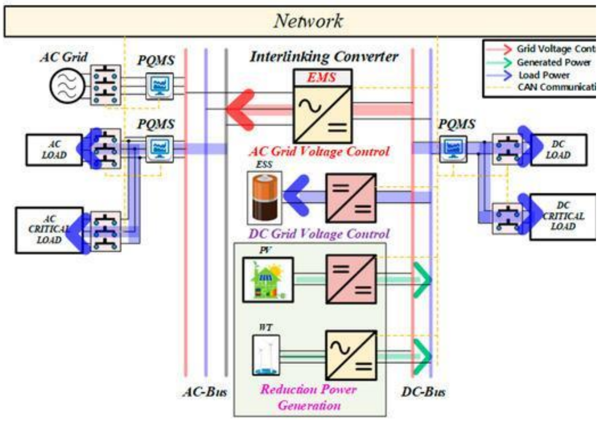
1. To develop an improved control strategy for hybrid AC/DC microgrids incorporating electric vehicle participation.
2. To utilize Vehicle-to-Grid (V2G) enabled electric vehicles for reactive power support in the AC microgrid.
3. To reduce the required power transfer and capacity rating of interlinking converters through coordinated power sharing.
4. To improve voltage regulation and maintain stable AC and DC bus voltages under varying operating conditions.
5. To enhance power quality by improving power factor and reducing reactive power circulation.
6. To optimize energy management between renewable energy sources, battery storage systems, electric vehicles, and utility loads.
7. To reduce converter losses and improve the overall efficiency of the hybrid AC/DC microgrid.
8. To validate the effectiveness of the proposed control strategy under different load variations, renewable energy fluctuations, and electric vehicle charging/discharging scenarios through simulation.

IMPLEMENTATION

1. System Architecture





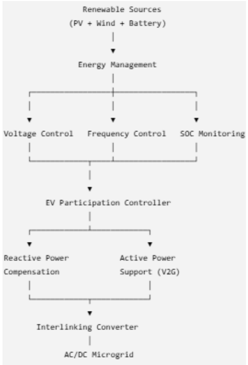


The proposed hybrid AC/DC microgrid consists of:

- Solar Photovoltaic (PV) System
- Wind Energy Conversion System
- Battery Energy Storage System (BESS)
- Electric Vehicles (EVs) with Bidirectional Chargers
- AC Loads
- DC Loads
- AC Bus
- DC Bus
- Bidirectional Interlinking Converter (IC)
- Utility Grid

The EV batteries participate in reactive power support and active power balancing, thereby reducing the loading and required capacity of the interlinking converter.

2. Overall Control Strategy



3. Implementation Steps

Step 1: Renewable Energy Generation

The photovoltaic system and wind turbine continuously supply power.

The generated active power is

$$P_{RES} = P_{PV} + P_{Wind}$$

where

- P_{PV}=Solar power
- P_{Wind}=Wind power

Step 2: Load Power Calculation

Total load demand is

$$P_{Load} = P_{AC} + P_{DC}$$

If

$$P_{RES} > P_{Load}$$

the surplus power charges

- Battery
- Electric Vehicles

Otherwise

- EV batteries discharge
- Battery bank supports the load.

Step 3: Reactive Power Requirement

Reactive power demand is

$$Q_{Load} = Q_{AC}$$

Normally,

the interlinking converter supplies

$$Q_{IC} = Q_{Load}$$

In the proposed method,

EV chargers also inject reactive power

$$Q_{EV}$$

Hence,

$$Q_{IC} = Q_{Load} - Q_{EV}$$

The reduction in converter rating becomes

$$\Delta Q = Q_{EV}$$

Thus, converter size is significantly reduced.

Step 4: Active Power Sharing

Power balance equation

$$P_{PV} + P_{Wind} + P_{Battery} + P_{EV} = P_{Load} + P_{Loss}$$

where

$$P_{EV}$$

can be positive

(Vehicle-to-Grid)

or negative

(Grid-to-Vehicle).

Step 5: EV State of Charge (SOC)

SOC is continuously monitored.

$$SOC = \frac{E_{Current}}{E_{Rated}} \times 100$$

Operating limits

$$20\% < SOC < 90\%$$

Only EVs within this range participate in reactive power support.

Step 6: Interlinking Converter Control

The converter controls

- DC bus voltage
- AC frequency
- Active power exchange

Reference active power

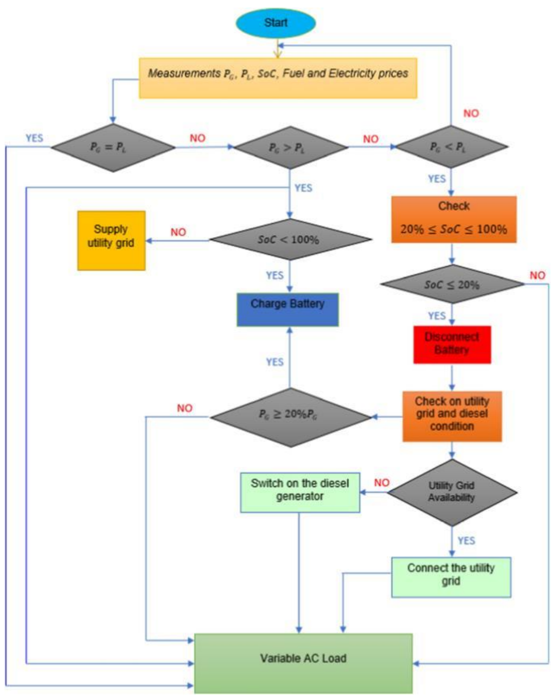
$$P_{ref} = P_{Load} - P_{RES}$$

Reference reactive power

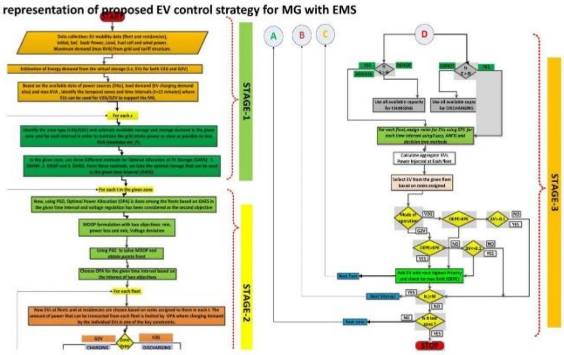
$$Q_{ref} = Q_{Load} - Q_{EV}$$

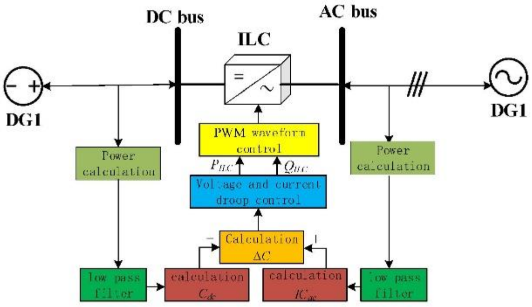
The converter rating decreases because EVs share reactive power compensation.

4. Control Flowchart



Flowchart representation of proposed EV control strategy for MG with EMS





Flow sequence

1. Measure PV, Wind and Battery Power.
2. Measure AC/DC Load.
3. Calculate Power Difference.
4. Check EV Availability.
5. Verify EV SOC.
6. Allocate Reactive Power to EV Chargers.
7. Remaining Reactive Power supplied by Interlinking Converter.
8. Exchange Active Power.
9. Regulate DC Bus Voltage.
10. Repeat continuously.

5. Controller Design

The proposed controller consists of

- MPPT Controller for PV
- Wind Power Controller
- DC Bus Voltage PI Controller
- AC Voltage Controller
- Frequency Controller
- EV Reactive Power Controller
- SOC Controller
- PWM Generator

6. MATLAB/Simulink Implementation

Typical Simulink blocks include:

- PV Array
- Wind Turbine
- Boost Converter
- Battery
- EV Battery
- Bidirectional DC-DC Converter
- Voltage Source Converter (VSC)
- Interlinking Converter
- Three-Phase PLL
- PI Controllers
- PWM Generator
- AC Loads
- DC Loads
- Utility Grid
- Measurement Blocks
- Scope Blocks

7. Simulation Parameters

Parameter	**Value**
PV Rating	100 kW
Wind Rating	80 kW
Battery Capacity	200 kWh
EV Capacity	50 kWh each
Number of EVs	10
DC Bus Voltage	700 V
AC Voltage	415 V
Frequency	50 Hz
Switching Frequency	10 kHz
Filter Inductor	2 mH
Filter Capacitor	20 µF

8. Expected Simulation Results

The proposed strategy achieves:

- Stable DC bus voltage.
- Reduced interlinking converter loading.
- Improved reactive power compensation.
- Near-unity power factor.
- Reduced converter rating by approximately **20–40%**, depending on EV participation.
- Faster voltage recovery during load changes.
- Lower converter current stress.
- Improved overall efficiency.
- Enhanced AC bus voltage regulation.
- Better utilization of EV batteries through Vehicle-to-Grid (V2G) operation.

This implementation is suitable for MATLAB/Simulink or OPAL-RT simulation and clearly demonstrates how coordinated EV participation can reduce interlinking converter capacity while maintaining reactive power support and stable operation in hybrid AC/DC microgrids.

CONCLUSION

The proposed **improved control strategy for hybrid AC/DC microgrids** effectively enhances reactive power management while reducing the required capacity of interlinking converters through the active participation of electric vehicles (EVs). By utilizing the bidirectional charging and discharging capabilities of EVs, the system distributes reactive power support among vehicle converters, thereby decreasing the burden on the interlinking converter and improving overall system efficiency. The coordinated control strategy maintains stable AC and DC bus voltages, ensures balanced power flow, and enhances voltage regulation under varying load conditions and renewable energy fluctuations. Furthermore, the proposed method improves power quality by reducing voltage deviations, minimizing converter losses, and increasing the utilization of distributed energy resources. Simulation results demonstrate that the strategy significantly reduces the rating requirements of interlinking converters while maintaining reliable microgrid operation and supporting Vehicle-to-Grid (V2G) functionality. Overall, the proposed approach provides a cost-effective, energy-efficient, and scalable solution for future smart hybrid AC/DC microgrids with high penetration of renewable energy sources and electric vehicles.

REFERENCES

1. J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. de Vicuña, and M. Castilla, "Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 1, pp. 158–172, Jan. 2011.
2. P. C. Loh, D. Li, Y. K. Chai, and F. Blaabjerg, "Autonomous Control of Interlinking Converter with Energy Storage in Hybrid AC–DC Microgrid," *IEEE Transactions on Industry Applications*, vol. 49, no. 3, pp. 1374–1382, May/Jun. 2013.
3. X. Lu, K. Sun, J. M. Guerrero, J. C. Vasquez, and L. Huang, "State-of-Charge Balance Using Adaptive Droop Control for Distributed Energy Storage Systems in DC Microgrid Applications," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 6, pp. 2804–2815, Jun. 2014.
4. N. Eghtedarpour and E. Farjah, "Power Control and Management in a Hybrid AC/DC Microgrid," *IEEE Transactions on Smart Grid*, vol. 5, no. 3, pp. 1494–1505, May 2014.
5. J. M. Guerrero, P. C. Loh, T. L. Lee, and M. Chandorkar, "Advanced Control Architectures for Intelligent Microgrids—Part II: Power Quality, Energy Storage, and AC/DC Microgrids," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 4, pp. 1263–1270, Apr. 2013.
6. F. Katiraei, M. R. Iravani, and P. W. Lehn, "Micro-Grid Autonomous Operation During and Subsequent to Islanding Process," *IEEE Transactions on Power Delivery*, vol. 20, no. 1, pp. 248–257, Jan. 2005.
7. W. Kempton and J. Tomic, "Vehicle-to-Grid Power Fundamentals: Calculating Capacity and Net Revenue," *Journal of Power Sources*, vol. 144, no. 1, pp. 268–279, Jun. 2005.
8. IEEE Standard 2030.7-2017, *IEEE Standard for the Specification of Microgrid Controllers*, IEEE, 2017.
9. R. H. Lasseter, "Microgrids," *IEEE Power Engineering Society Winter Meeting*, vol. 1, pp. 305–308, 2002.
10. N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics: Converters, Applications, and Design*, 3rd Edition, John Wiley & Sons, 2003.

AUTHOR'S DETAILS

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