Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

Fuel Cell with Battery Storage Microgrid System Based on Green Energy in MATLAB

Dr. J P Sridhar
Department of EEE SJB Institute of Technology
Bengaluru, India 560060

Ganashree GT
Department of EEE SJB Institute of Technology
Bengaluru, India 560060

Ankitha C
Department of EEE SJB Institute of Technology
Bengaluru, India 560060

Ankith Gowda GR
Department of EEE
SJB Institute of Technology
Bengaluru, India 560060

Vaishnavi M
Department of EEE
SJB Institute of Technology
Bengaluru, India 560060

***Abstract*—This paper presents a comparative technical analysis of hybrid photovoltaic (PV) and fuel cell (FC)-based microgrid systems, integrating energy storage and advanced power electronics for stable and sustainable power generation. Drawing on recent studies [1]–[4], the report examines modeling approaches, system architectures, and performance metrics of hybrid microgrids simulated primarily using MATLAB/Simulink. Results highlight that PV/FC hybrid systems exhibit high efficiency, low emissions, and operational resilience under both islanded and grid-connected modes. Moreover, incorporating advanced power conversion techniques, such as multilevel inverters and adaptive control algorithms, significantly enhances power quality and system reliability. The study concludes that integrating PV and FC sources with battery storage offers a robust pathway for future green microgrid development.**

***Index Terms*—Fuel cell, photovoltaic, battery storage, hybrid microgrid, MATLAB/Simulink, renewable energy, power electronics**

I. INTRODUCTION

The global energy landscape is transitioning towards renewable energy integration due to increasing environmental concerns and the depletion of fossil fuels. Traditional centralized grids face limitations in flexibility, reliability, and environmental sustainability. As a result, microgrids—localized, controllable networks of distributed energy resources (DERs)—have emerged as a viable solution for decentralized power generation.

Among hybrid configurations, systems combining photovoltaic (PV) and fuel cell (FC) technologies have gained attention for their complementary characteristics. PV arrays harness solar energy, offering zero-emission electricity during daylight hours, while fuel cells deliver high-efficiency, on-demand power with water as the only by-product. When integrated with a battery energy storage system (BESS), such microgrids achieve enhanced reliability, improved transient response, and reduced dependence on the main grid [1], [2].

The objective of this paper is to synthesize and comparatively analyze PV/FC hybrid microgrid systems based on published research, focusing on component modeling, control design, performance in different operating modes, and efficiency optimization.

II. SYSTEM ARCHITECTURE AND COMPONENT MODELING

A hybrid PV/FC microgrid consists of three main subsystems—generation, storage, and power conversion—interconnected via a common DC bus. Accurate modeling of these components ensures realistic simulation and stable real-world performance.

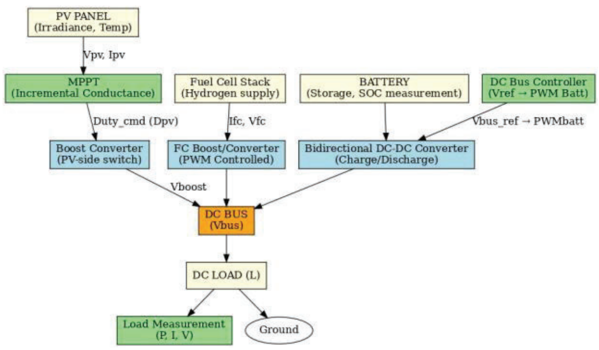

Fig. 1. Block diagram of the Fuel Cell with Battery Storage Microgrid System

A. Photovoltaic (PV) Array Modeling

Photovoltaic systems convert sunlight directly into electricity via the photovoltaic effect. The output characteristics of a PV cell are governed by a nonlinear current-voltage (I-V) relationship, expressed as [2]:

$$I = I_{PH} - I_S \left[\exp\left(\frac{q(V + IR_S)}{KT_C A} \right) - 1 \right] - \frac{V + IR_S}{R_{SH}} \quad (1)$$

where I and V are the cell output current and voltage, respectively, I_{PH} is the photocurrent, and I_S is the saturation current.

Environmental dependencies are modeled by:

$$I_{PH} = [I_{SC} + K_I(T_C - T_{Ref})]\lambda \tag{2}$$

$$I_S = I_{RS}\left(\frac{T_C}{T_{Ref}}\right)^3 \exp\left(\frac{qE_G(1/T_{Ref} - 1/T_C)}{kA}\right) \tag{3}$$

PV modules are interconnected in series and parallel to achieve desired power levels. Table **??** summarizes the configurations presented in major studies. [15]

B. Fuel Cell (FC) System Modeling

Proton Exchange Membrane Fuel Cells (PEMFCs) are widely used in microgrids for their low operating temperature and fast response. The cell voltage is given by:

$$E = E_{\text{Nernst}} - V_{\text{act}} - V_{\text{ohm}} - V_{\text{con}} \tag{4}$$

where E_{Nernst} is the ideal thermodynamic potential, and V_{act}, V_{ohm}, and V_{con} represent activation, ohmic, and concentration losses, respectively.

Typical implementations include 6 kW PEMFC stacks for small-scale systems [1], [2] and up to 50 kW stacks for larger grid-integrated setups [3].

C. Battery Energy Storage System (BESS)

BESS ensures stability by compensating for transient variations in generation and demand. Two technologies are commonly modeled:

- **Lithium-ion (Li-ion):** High efficiency and long life; modeled using the modified Shepherd equation [1].
- **Lead-Acid:** Lower cost and reliability for short-term backup, as used in [3].

D. Power Conversion Interfaces

DC/DC converters regulate variable source voltages to a common DC bus, while DC/AC inverters convert DC to grid-compatible AC.

Boost Converters: Closed-loop boost converters maintain a regulated 400 V DC bus for stable operation [9]. Advanced four-level topologies combined with Adaptive Neuro-Fuzzy Inference System (ANFIS) MPPT controllers further enhance power extraction efficiency [4].

Inverters: Three-phase Voltage Source Inverters (VSI) are commonly used for grid interfacing. Multilevel Inverters (MLI) with 5-, 7-, and 15-level configurations achieve Total Harmonic Distortion (THD) below 5%, enhancing power quality [4].

E. System Operation Flowchart

The operation of the hybrid microgrid system involves coordinated energy management among the photovoltaic (PV), fuel cell (FC), and battery energy storage subsystems. The control algorithm dynamically selects the most suitable power source depending on load demand and generation availability. The flowchart in Fig. **??** outlines the system's logical sequence of operation. [**?**], [13]

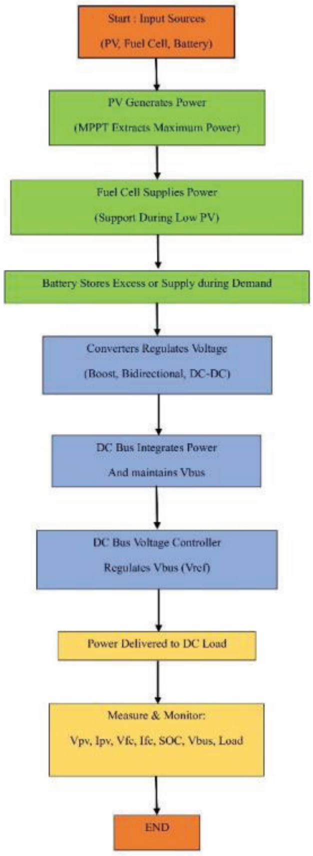

Fig. 2. Flow chart of the Fuel Cell with Battery Storage Microgrid System

During daytime operation, the photovoltaic array serves as the primary power source. If solar generation is insufficient, the fuel cell activates to maintain supply continuity. The battery energy storage system (BESS) acts as both a buffer and a backup—discharging during high demand or low generation and charging during surplus conditions. The control logic ensures smooth power transitions and optimal utilization of renewable sources. [5]

F. Simulation Model

To evaluate the performance of the hybrid fuel cell with battery storage microgrid, a detailed MATLAB/Simulink model was developed. The simulation integrates electrical, control, and power electronic subsystems to replicate realistic operating conditions. [10]

The Simulink model is composed of the following major components:

- **Fuel Cell Subsystem:** Modeled as a proton exchange membrane (PEM) fuel cell using stack parameters derived from manufacturer data. A DC/DC boost converter regulates the fuel cell output voltage to the DC bus level (400 V).
- **Battery Energy Storage:** Implemented using the Simscape Electrical battery block with a lithium-ion or lead-acid equivalent circuit. A bidirectional DC/DC converter

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

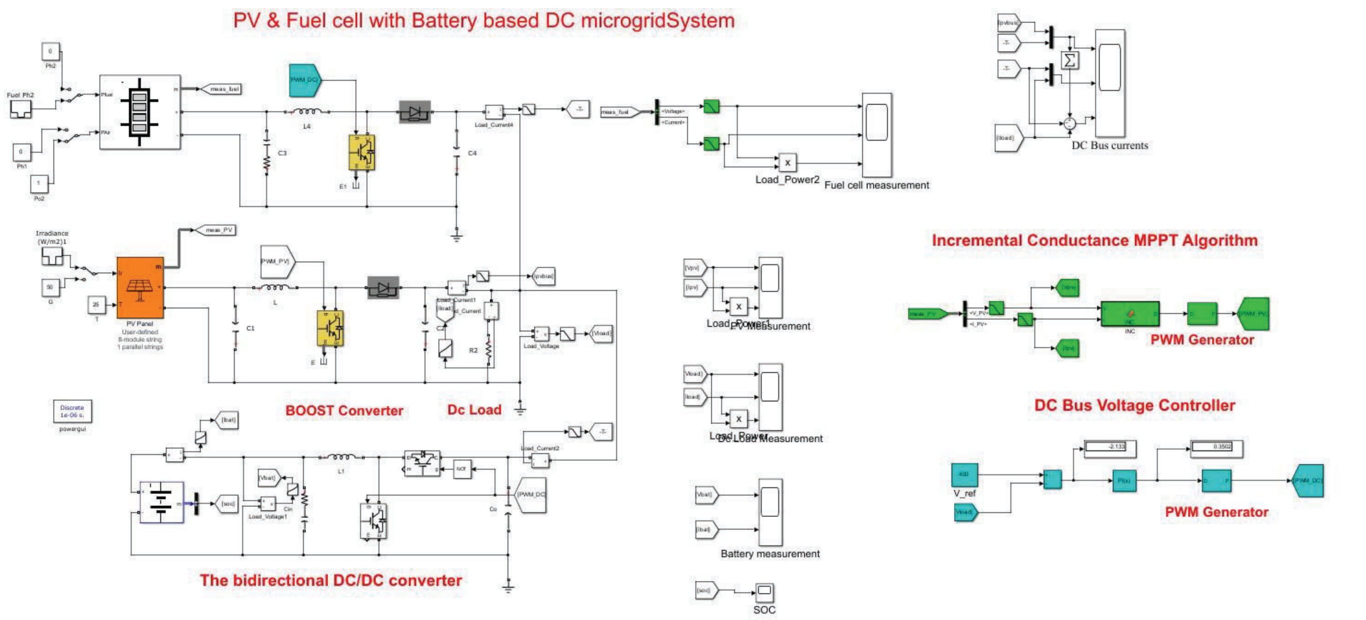

Fig. 3. MATLAB/Simulink model of the hybrid fuel cell with battery storage microgrid system.

interfaces the battery to the DC bus, enabling both charging and discharging modes.

- **Photovoltaic Array (optional integration):** For hybrid configurations, a PV array model with MPPT control is connected in parallel through an independent boost converter.
- **DC Bus and Link Capacitor:** The DC bus consolidates power from all DC sources and storage devices. A large DC link capacitor maintains voltage stability and smooths transient disturbances.
- **Inverter and Load:** A three-phase voltage source inverter (VSI) converts DC power to AC for supply to local loads or the utility grid. PWM control maintains sinusoidal output with low harmonic distortion.
- **Control Subsystem:** Supervisory control logic (implemented via Simulink logic blocks or MATLAB scripts) monitors load demand, source availability, and state of charge (SoC) to coordinate source selection according to the flowchart fig 2 [5]

The simulation runs under varying load and generation scenarios, including:

1) **Steady-State Operation:** Constant load with adequate fuel cell supply.
2) **Dynamic Transition:** Step changes in load demand to test system response.
3) **Source Switching:** Transition between PV, fuel cell, and battery under different irradiance or hydrogen supply conditions.
4) **Grid Connection:** Synchronization of inverter output to a 415 V, 50 Hz grid through a phase-locked loop (PLL) control.

Simulation results demonstrate stable DC bus voltage regulation, smooth load transitions, and minimal total harmonic distortion (THD) at the inverter output. The MATLAB environment facilitates time-domain visualization of voltage, current, and power waveforms, as well as state-of-charge dynamics for the battery subsystem. [6]

III. PERFORMANCE ANALYSIS IN OPERATIONAL MODES

A. *Islanded Mode*

In standalone mode, the microgrid relies solely on local generation and storage. Podder et al. [1] demonstrated that their 73 kW PV/FC/BESS system could sustain a 43 kW AC load with stable voltage and current waveforms. The system achieved steady-state operation after a 2.1 s transient, during which the battery discharged to maintain power balance.

B. *Grid-Connected Mode*

When synchronized with the utility grid, the hybrid microgrid can export surplus power or draw energy during deficits. Load flow results for the IEEE 13-bus feeder showed a net injection of 72.65 kW real power with stable voltage and current [1].

Table 1 I summarizes representative grid performance results from [1], [3].

These results confirm effective power sharing, stable output, and successful islanding capability.

IV. SYNTHESIS OF FINDINGS AND CONCLUSIONS

A. *System Stability and Reliability*

All reviewed studies confirm stable microgrid operation under both islanded and grid-connected modes. The inclusion

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

TABLE I
COMPARISON OF GRID-CONNECTED AND ISLANDED OPERATION

Parameter	Grid-Connected	Islanded
DG Voltage (V)	415	415
DG Current (A)	35	5
Active Power (W)	4300	3000
Reactive Power (VAR)	25000	1500
Grid Voltage (V)	11000	6000
Grid Power Draw (W)	600	14

of BESS enhances reliability by compensating for solar intermittency and load fluctuations [1], [12].

B. Power Quality and Efficiency

Advanced inverter designs greatly improve output waveform quality. According to [7], efficiency measurements for multilevel inverters were:

- 5-level MLI: 94.76%
- 7-level MLI: 94.26%
- 15-level MLI: 93.87%

Although efficiency slightly decreases with inverter complexity due to increased conduction losses, THD is significantly reduced, improving power quality.

V. EXPERIMETAL RESULTS

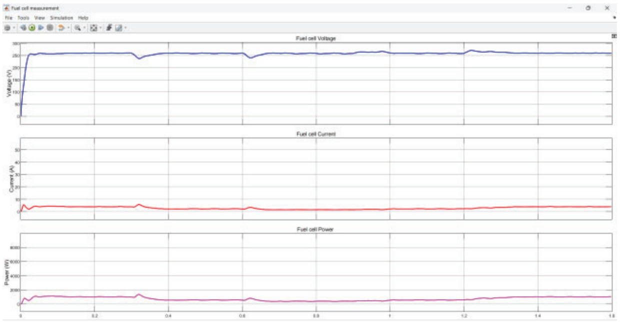

Fig. 4. Fuel cell voltage, current, and power characteristics during microgrid operation.

The fig 4 shows three graphs in a simulation window titled ”Fuel cell measurement”.

- The top graph shows a blue line representing Fuel cell Voltage, staying around 250V after an initial spike. - The middle graph shows a red line for Fuel cell Current, staying around 10A with minor fluctuations. - The bottom graph shows a purple line for Fuel cell Power, staying around 1000W (though the scale suggests it could be less, like 500-1000W based on the graph). [7]

The fig 5 shows a simulation window titled ”Battery measurement” with two graphs.

- The top graph shows Battery Voltage (blue line) which starts low, spikes to around 250V, and then stabilizes. - The bottom graph shows Battery Current (red line) which fluctuates between around -5A to 5A with some peaks.

The fig 6 shows a simulation of DC load measurement with three graphs: DC Bus Voltage, DC Load Current, and DC Load Power.

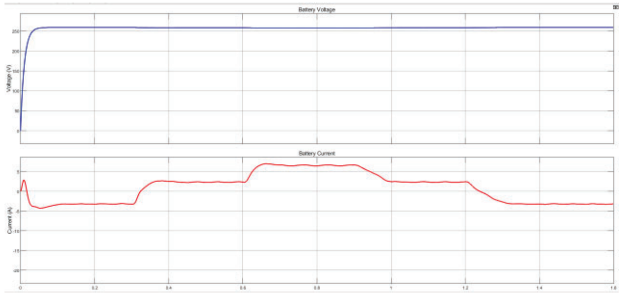

Fig. 5. Battery current, battery voltage during microgrid operation.

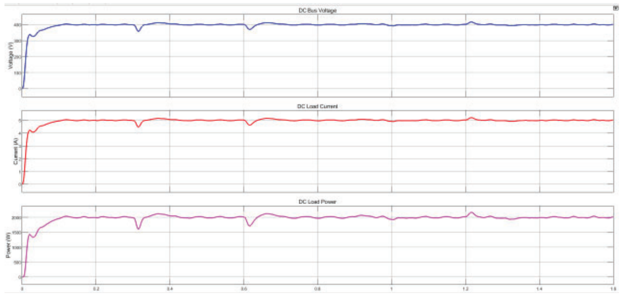

Fig. 6. DC Bus current, DC Bus voltage and DC Load power characteristics during microgrid operation.

- DC Bus Voltage (blue line): Starts at around 300V, spikes to 400V, and then stabilizes with minor fluctuations. - DC Load Current (red line): Ramps up to 5A and stabilizes with minor dips. - DC Load Power (pink line): Increases to 2000W and stabilizes with minor fluctuations. [12]

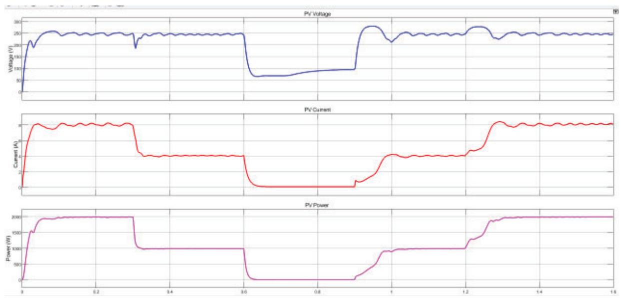

Fig. 7. PV current, PV voltage and PV power characteristics during microgrid operation.

The fig 7 shows the PV (Photovoltaic) measurement with three plots: PV Voltage, PV Current, and PV Power over time.

- PV Voltage: The blue plot shows voltage fluctuating around 250V with a dip to about 50V between 0.6s and 1s. - PV Current: The red plot shows current dropping from about 8A to 1A between 0.6s and 1s. - PV Power: The pink plot shows power dropping from about 1800W to near 0W between 0.6s and 1s, probably

The fig 8 shows a simulation plot of DC bus currents with three subplots:

1. PV fuel cell Converter current: - Two lines are plotted: blue and orange. - Current (A) is on the y-axis, and time is on the x-axis. - The blue line starts high (5A), dips, and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

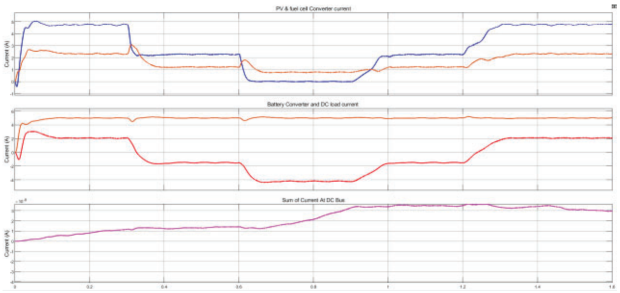

Fig. 8. PV and fuel cell current, Battery current DC load current and Sum of current at DC Bus characteristics during microgrid operation.

then stabilizes with fluctuations. - The orange line is steadier around 2-3A.

2. Battery Converter and DC load current: - Two lines: orange and red. - The orange line is steady around 4A. - The red line fluctuates, going from positive to negative values.

3. Sum of Current At DC Bus: - One pink line. - Current values are very small (10A-8 A). - The line shows a slight increase and then stabilizes.

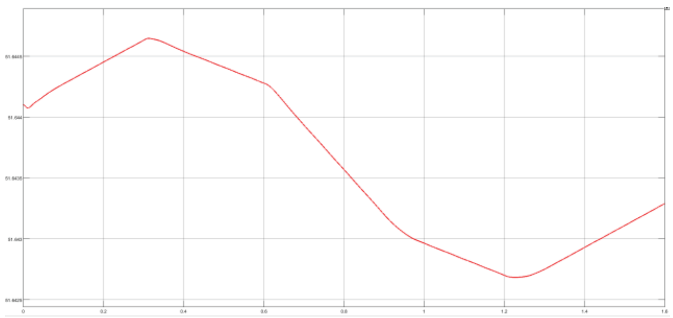

Fig. 9. State of charge characteristics during microgrid operation.

VI. CONCLUSION

Hybrid PV/FC microgrids demonstrate exceptional stability, scalability, and eco-efficiency. When integrated with intelligent energy storage and advanced multilevel inverter topologies, they provide clean, reliable energy for both standalone and grid-tied applications. Continued development in power electronics, control algorithms, and energy management will further enhance the viability of such green microgrid systems for future sustainable power networks.

ACKNOWLEDGMENT

The authors express their gratitude to the Department of Electrical and Electronics Engineering, SJB Institute of Technology, Bengaluru, for their support in preparing this study.

REFERENCES

[1] A. K. Podder, K. Ahmed, N. K. Row, and M. Habibullah, “Design and simulation of a photovoltaic and fuel cell based micro-grid system,” *ResearchGate*, Mar. 2019.

[2] R. Chowdhury and T. Boruah, “Design of a micro-grid system in MATLAB Simulink,” *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 4, no. 7, 2015.

[3] A. Khamis, M. R. A. Ghani, C. K. Gan, and H. N. M. Shah, “Modeling and analysis of fuel cell with battery storage microgrid system based on green energy,” *Indian J. Sci. Technol.*, vol. 11, no. 48, 2018.

[4] C. Dhanamjayulu, S. Padmanaban, M. R. Kumar, and P. Sanjeevikumar, “Multilevel inverter-based hybrid renewable energy system with ANFIS-MPPT control,” *IEEE Access*, vol. 8, pp. 139621–139633, 2020.

[5] . Malhotra DP. Modelling and simulation of fuel cell based dc microgrid; 2014. p. 1–51.

[6] . Ahmed M, Amin U, Aftab S, Ahmed Z. Integration of renewable energy resources in microgrid. Energy and Power Engineering. 2015; 7(1):12–29. https://doi.org/10.4236/ epe.2015.71002

[7] . Chowdhury R, Boruah T. Design of a microgrid system in Matlab/Simulink. International Journal of Innovative Research in Science, Engineering and Technology. 2015; 4(7):1–8.

[8] . Singh A, Surjan BS. Microgrid: A review. International Journal of Research in Engineering and Technology. 2014; 3(2):1–14. Vol 11 (30) — August 2018 — www.indjst.org

[9] . Krishna SV, Suman T. A new PV/fuel cell based bidirec tional converter for microgrid applications. International Journal of Emerging Engineering Research and Technology. 2014; 2(5):121–9.

[10] . Jaim R, Singh D, Kumar V. Design and modeling of fuel cell using Matlab Simulink. 2015; 2(8):19–22

[11] . Feroldi D, Basualdo M. Description of PEM fuel cells system. Springer-Verlag London Limited; 2012. p. 1–25.

[12] . Bahmani-Firouzi B. Optimal sizing of battery energy storage for microgrid operation management using a new improved Bat Algorithm. Electrical Power and Energy Systems. 2014; 56:42–54. https://doi.org/10.1016/j.ijepes.2013.10.019

[13] . Aravindan P, Subbulakshmi G. Uninterrupted supply and frequency support for local load in Microgrid by Battery Energy Storage System (BESS). International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. 2015; 4(2):1–7.

[14] . Joseph A, Shahidehpour M. Battery storage systems in electric power systems. IEEE Power Engineering Society General Meeting; 2006. p. 1–8. https://doi.org/10.1109/ PES.2006.1709235

[15] . Wu G, Sun H, Pan L. Lithium-ion battery. BYD Co Ltd Shenzhen BYD Auto RD Co Ltd; 2014