**Hierarchical Energy Management System for a Microgrid**

**Project Overview**

This project presents a hierarchical Energy Management System (EMS) designed for a microgrid consisting of 100 residential units. Each unit is equipped with photovoltaic (PV) panels and electric vehicles (EVs), and the entire system includes a centralized wind turbine and an Energy Storage System (ESS).

The EMS is organized into three control levels:

* **Level 1** operates locally at the household level, managing PV production, household consumption, and EV charging or discharging decisions.
* **Level 2** aggregates power data from 10 houses and relays it to the central controller.
* **Level 3** supervises the entire microgrid, managing energy flows from the wind turbine, the ESS, and the available EVs.

The goal is to dynamically balance energy generation and consumption under different conditions using a **power-based control strategy**, as opposed to conventional current- or voltage-driven models.

**Scenario 1 – Normal Operation**

In this configuration, all components are available: wind turbine, PV panels, EVs, and ESS. The wind turbine delivers variable energy, PV contributes during the day, and the ESS is initialized at a mid-level state of charge. EVs are connected and ready to charge.

The EMS prioritizes energy allocation:

* First, surplus energy charges EVs and ESS.
* Then, if demand increases, the ESS discharges.
* EV discharging is only enabled when required and safe (SOC > 40%).

Each control level plays its role:

* Level 1 balances the power for each household.
* Level 2 communicates requests and feedback between houses and the central EMS.
* Level 3 responds by optimally distributing available power sources.

The simulation confirms correct power flow, no overloads, and successful charge balancing across all devices.

**Scenario 2 – Wind Turbine Failure**

In this scenario, the wind turbine is assumed to be offline (e.g., due to maintenance or fault). All other components operate normally.

Level 3 immediately recognizes the loss of wind input and compensates by using the ESS. The SOC of the ESS gradually decreases as it supplies energy. Once ESS resources become limited, the EMS evaluates the availability of EVs and authorizes controlled discharging — provided their SOC exceeds 40%.

Throughout the simulation:

* PV continues to supply energy during daylight.
* ESS fills the gap left by the turbine.
* EVs serve as a backup buffer, activated only when needed.

Despite the missing wind input, the EMS maintains full operational stability, confirming its robustness and layered fallback logic.

Conclusion

The proposed three-level EMS demonstrates reliable performance across different operating scenarios. Instead of focusing on direct control of voltage or current values, the system operates based on active power signals, which implicitly reflect voltage and current through power equations. This approach allows the EMS to adapt efficiently to real-time fluctuations in energy demand and availability, while still respecting electrical constraints.

The modular and scalable architecture makes it suitable for larger deployments and integration into future smart grid infrastructures. The system handles normal and faulty conditions without interruptions or instability, proving its value as a resilient and intelligent energy management solution.

Although the system currently relies on lookup tables to simulate input signals such as wind speed, irradiance, and load demand, most of these datasets are based on realistic values or can easily be replaced with actual measurements. This ensures both flexibility and applicability to real-world conditions.

Due to space limitations allowing only four figures, the report focuses on two representative scenarios. However, the EMS was tested under multiple other configurations, confirming its robustness across a wide range of conditions. The project is planned to be extended with additional functionalities and scenarios to further enhance decision-making capabilities.