# Energy management system for PV-Battery microgrid based on model predictive control

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**ABSTRACT**

There had been increase of the usage of renewable energy sources to supply electricity in remote areas. However, microgrid consists of renewable sources such as solar Photovoltaic (PV) poses challenges for a reliable energy supply due to its intermittent nature. This paper presents a microgrid model with Energy Management System based on Model Predictive Control (MPC). The microgrid comprises of PV, and battery storage system. The goal of the EMS is to deliver a reliable and optimal generation from multiple sources in the microgrid. Moreover, the MPC will also provide controls for the battery charging for a smooth PV output. The model simulated based on actual load profile and renewable resource such as solar radiation. Several disturbances such as variation of load, generation and PV shading has been simulated to measure the performance of the EMS. The results illustrate the system ability to exhibits robust performance in variety of conditions.



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## 1. INTRODUCTION

The growth of energy demand in remote areas has triggered installation of microgrid systems. The clean energy such as PV, small hydro, wind and biomass has been chosen to provide energy in these areas. Typically, microgrid is a low voltage network comprises of distributed energy resources (DERs) alongside battery storage system and backup diesel generators [1]. It can be either operates in grid-connected or islanded mode. However, standalone microgrid system were used in remotes areas due to unavailability of transmission network. Microgrid offer advantages such as mitigation of $CO_2$, outages and line losses [2].

Nowadays, there had been an increment in the integration of renewable energy sources in a microgrid. Multiple energy sources are integrated in the microgrid to have for a reliable energy supply. However, introduction of several generations in the microgrid causes other challenges such as inefficient power deliveries because it needs scheduling, control and proper sizing. Hence, EMS is crucial for a microgrid in where it covers both supply and demand side management while providing reliable, sustainable and economical operation. Moreover, EMS provide other benefits such as energy savings, frequency regulation, reactive power support, cost-reduction and reduction of greenhouse gasses [3].

There had been many control strategies used for EMS in a microgrid. Many control schemes are based on conventional centralized EMS. Centralized EMS (CEMS) comprises of communication network to monitor the DERs where a supervisory controller will send commands to the local controller to optimize the energy usage [4]. Various EMS algorithms have been used to optimize microgrid operation as well as minimizing operation cost and maximizing profits. For example, Jing Wang et al. uses state machine for microgrid control [5]. The EMS aims to improve the transient performance during transition operations. Damian Giaouris at al. used multiple stochastic methods to control assets such as energy storage in the microgrid [6]. The system also includes forecasting tools and demand response management to optimize the system performance. Similarly, Dongxiao Wang proposes a two-stage energy management strategy to microgrid with high renewable energy penetrations [7]. A Particle Swarm Optimization has been used by Sardou et al. for optimal EMS considering VAR compensation mode for PV inverters [8]. Meanwhile, Mehdi Tavakoli et al. incorporates Conditional Value at Risk (CVaR) in the EMS control scheme for handling intermittent PV generations and electricity price [9]. Hybrid Fuzzy system also been used to for a robust EMS. For instance, Kutaiba S. El-Bidairi et al. used Grey Wolf Optimiser to enhance the Fuzzy control in the EMS by setting the Fuzzy membership functions and rules [10]. The author in develops a Dynamic Energy Management Model based on hetero-functional graph theory for a microgrid system [11]. There were also other method such as Vitality Administration Calculation and Multiple Objective Optimizations for energy management in a microgrid [12, 13].

Recently, there has been extensive research conducted for a Decentralized EMS (DEMS). For example, Fatima Zahra Harmouch et al. develop a multiagent systems (MAS) DEMS for balancing the power generations and load demand [14]. Furthermore, M. Reyasudin Basir Khan et al. used MAS based EMS to optimize the power generations of a microgrid system comprises of PV, mini-hydro, diesel and battery storage system for a resort island in South China Sea [15], [16]. The author uses actual load profile of the island and simulates the performance of the proposed EMS based on several disturbances [17]. Moreover, author in [18] presented an ontology-driven MAS based EMS for monitoring and optimizing building microgrid with multiple energy sources. MAS also used for distribution level in microgrid for power delivery management [19]. Many researchers compared performance of both CEMS and DECMS and concluded the latter have robust performance [20-22].

This paper focuses on the development of MPC based EMS for a hierarchical control scheme in a CEMS. There had been several researchers proposed MPC as a control algorithm in the EMS for optimizing power generations. For example, author in used MPC for a PV microgeneration [23]. Additionally, a robust MPC was used to control PV and wind generations in an island microgrid [24]. A hierarchical MPC with two layer controller also used in a building microgrid to fulfill the building energy needs with multiple energy sources [25].

This paper organized as follows: Section 2 describes the microgrid model. Section 3 presents the MPV control scheme for the EMS. Section 4 discusses the results comprises of the performance evaluation of the MPC based EMS. Finally, Section 5 concludes this paper and summarizes the findings.

## 2. MICROGRID MODEL

### 2.1. Microgrid Architecture

In this study, a single phase microgrid system comprises of PV and battery storage system has been modeled. The microgrid architecture is shown in Figure 1. Battery controller has been used to manage the charging process. The storage act to absorb the surplus power from the power generations and provides power when there is power shortage in the microgrid. The PV array connected to distribution network through a pole transformer that lowers the voltage from 11 kV to 230 V. The PV system converted to single phase AC for power distribution. The microgrid control strategy assumes the PV array alongside battery storage system provide enough power for the energy demand and does not entirely depend on the power grid.

### 2.2. Microgrid Model

The microgrid system was modeled and simulated in MATLAB Simulink SimPowerSystems as shown in **Error! Reference source not found.**. There are six key components in the microgrid model such as PV system, battery storage, battery controller, loads, distribution network and power grid. Phasor model were used to simulate 24-hour scenario with fast simulation time. Meanwhile, power electronics components are not modeled.

The microgrid is a PV-battery system with a capacity of 50 kW that is contributed by the PV array. The battery controller uses load dispatch strategy where excess renewable energy generation will charge the battery. If the renewable energy configuration does nor able to feed the load, the main grid will be used to supply energy to the loads. The electrical system comprises of 50 Hz, 230 V single phase network. The small microgrid system were developed mainly to supply energy for the indigenous people located in remote area.

The PV system are modeled as follows:

$$P_{Out} = GFAe \tag{1}$$

where $P_{out}$ is the power output from PV array (kW), $G$ is solar irradiance ($W/m_2$), $F$ is the partial shading factor (0-1), $A$ is the PV area size ($m^2$) and $e$ is the efficiency of PV panel (0-1).

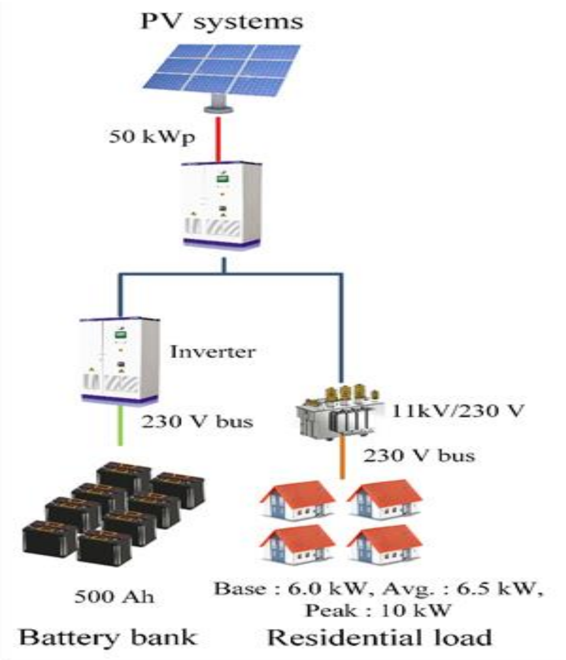


Figure 1. Microgrid schematic

The battery storage system is modeled as follows:

$$SOC = 100\left[1 - \left(\frac{1}{Q}\int_0^t i(t)\,dt\right)\right] \quad (2)$$

$$B_{AH} = \frac{1}{3600}\int_0^t i(t)\,dt \quad (3)$$

where $SOC$ is the percentage of the battery capacity, $i$ is the battery current, $Q$ is the rated capacity (Ah), and $B_{AH}$ is the battery ampere-hour.

The load comprises of residential load. There are three residential loads modeled in the microgrid system to simulate the energy demand in a typical rural area. The loads also use to simulate the EMS performance in variety of load conditions.

## 3. MODEL PREDECTIVE CONTROL

The microgrid system utilizes MPC based EMS that aims to optimize the power dispatch of the PV and battery storage system. The EMS will take into account the renewable resource such as solar radiation, and load demand in determining the best possible power delivery needed. There is also global objective function that considers energy cost, load demand, power generation and power losses to determine optimal power dispatch. In this work, MPC framework proposed to handling constraints and control, thus, also optimizes the cost function. The global functions are shown as below:

$$minimize\ f = \sum_{t=1}^{T}\sum_{i=1}^{N_G} c_{it}P_{it} \quad (4)$$

$$subject\ to\ \sum_{t=1}^{T}\sum_{i=1}^{N_G}\left(P_{it} - P_{load,it} - P_{losses,it}\right) \quad (5)$$

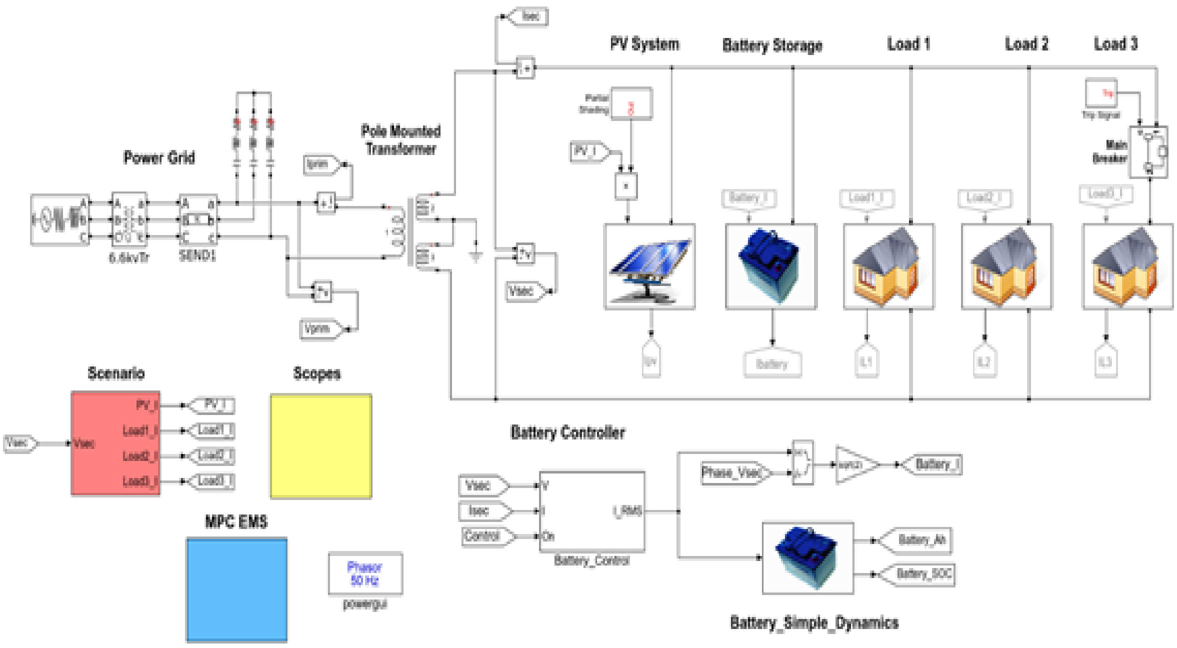


Figure 2. Simulink microgrid model

where energy cost denoted by cit, the power output, load demand and power losses denoted by Pit, Pload, it and Plosses, it respectively. T is the total interval in a day (24) and NG is the total number of generations.

The MPC considers the global function over period with respect to the defined constraints to minimize the energy cost. The MPC scheme is illustrated in the flow chart shown in Figure 3.

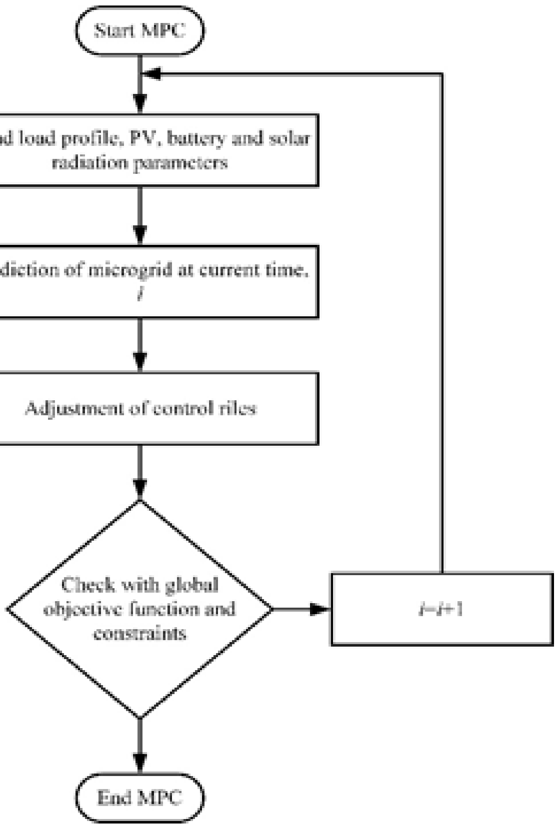


Figure 3. MPC control scheme

## 4. SIMULATION AND RESULTS

The input for this model is solar radiation and load profile. The MPC based EMS will optimize the power dispatch accordingly based on the input parameters. The solar radiation and load profile input is shown in Figure 4 and Figure 5. There are no solar power generation from 20h to 4h. The load follows typical profile for remote location with peaks occurs at 9h, 19h and 22h where the demand is 6.5 kW, 7.5 kW and 7.5 kW respectively. The battery controller by controller from 0h to 12h and from 18h to 24h. The active power from pole mounted transformer set to 0. So, the battery controller tracks the current to ensure the active power from the grid is always zero. The battery storage system supplies power when the total generation from microgrid insufficient to meet the load demand. The storage will absorb excess power from the microgrid when the load demand is low. The battery control is not performed from 12h to 18h. Therefore, the battery state-of-charge (SOC) is constant and there is no charging or discharging performed by the controller. However, when there is shortage of power, the controller will discharge the battery to supplement the demand. When there is surplus generation, it will be used to charge the battery. One of the house loads is OFF for 10 seconds to introduce disturbance into the microgrid. There is a voltage spike but was quickly recovered by the MPC based EMS. The system recovered within 30 seconds. The microgrid system outputs is shown in Figure 6.

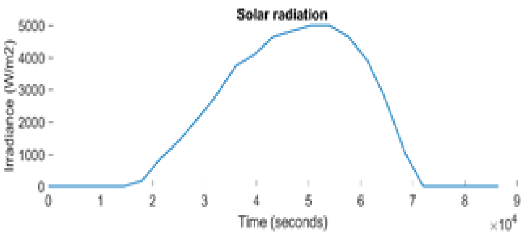


Figure 4. Daily solar radiation

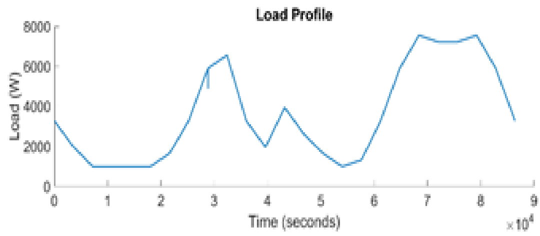


Figure 5. Daily load profile

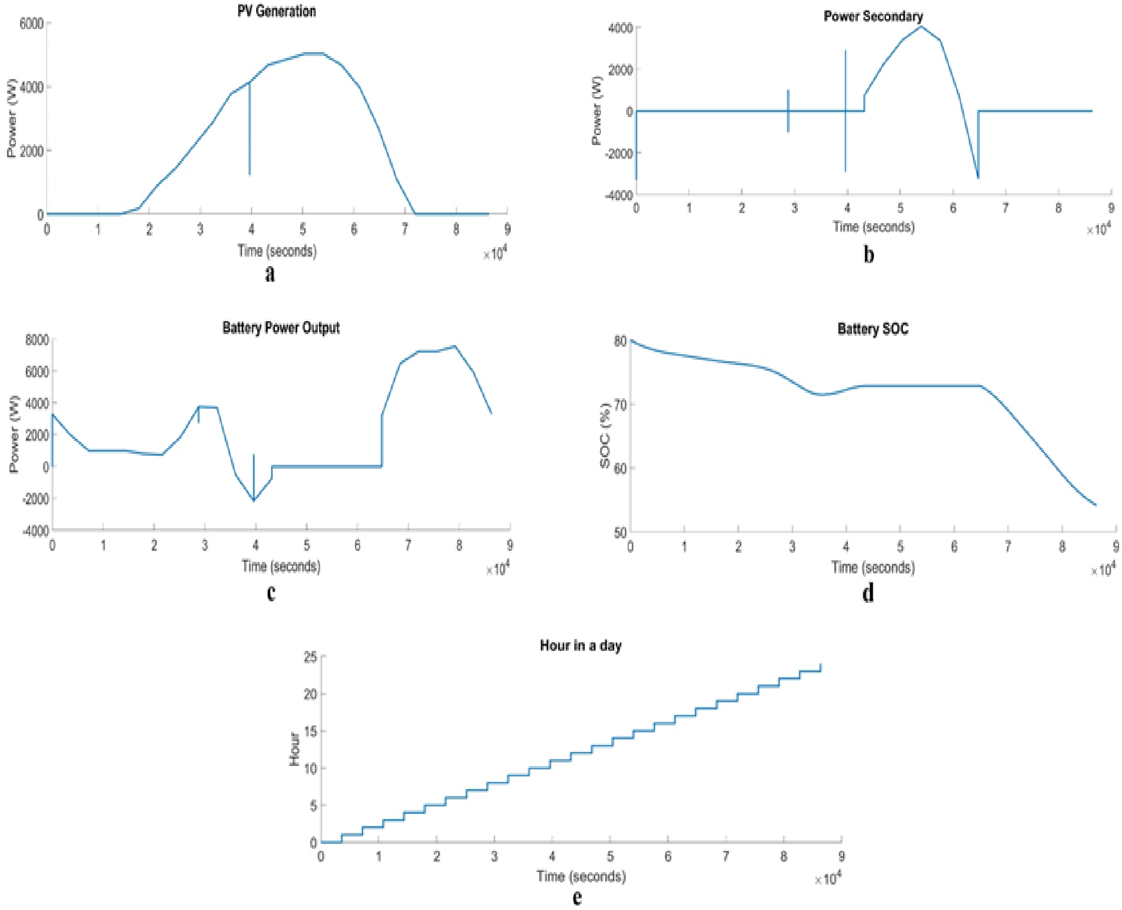


Figure 6. Simulation results

## 5. CONCLUSION

The proposed MPC based EMS shows robustness and reliability in handling changes in loads and variability of renewable resources. Moreover, it showcases fast response in handling disturbances in the microgrid.


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