

# Dispatch Strategy for Grid-connected Micro-wind Turbine Generators with Battery: Case Study in Malaysia

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**Abstract** In recent years, Malaysian government has been searching for an opportunity to realize the first wind farm in Malaysia to achieve 20% penetration of renewable energy by 2025. Even though Malaysia experiences low average wind speed, but rapid advancement of micro-wind turbine technology promises a potential enhancement of wind harvesting in Malaysia in the near future. Concerning of high wind penetration to the grid, severe technical problems because of its fluctuating and intermittent nature will affect the power system stability. In view of that, this paper proposes a dispatch strategy for a wind farm comprising micro-wind turbine generators supported by a battery to minimize the fluctuation where for a monthly interval, a different value of reference power is followed. In parallel, the lower and upper constraints of battery state-of-charge must be satisfied. The proposed strategy is validated using the real wind data measured at Mersing, Malaysia. The results reveal that the proposed strategy successfully reduces the fluctuation and achieves the reference power for most of the intervals while ensuring the battery operates within a safe operating region. Using the simulation results, the payback period is estimated, which exposes that this project as an example, requires about 20 years of period to reimburse the capital expenditure.

**Keywords** Dispatch Strategy, Micro-wind Turbine Generator, Battery, State-of-charge, Payback Period

## 1. Introduction

World electricity generation, including Malaysia, is highly dependent on fossil fuels despite the fact that over-consuming may lead to severe air pollution emissions. For that reason, green energy resources, also known as renewable energy (RE) such as wind, solar, biomass, and hydropower, is explored extensively. Alongside their cleanliness, they also offer lower costs and naturally replenished. Among these resources, wind energy is one of

the most favorable prospects for its lower cost of investment, hence widely studied in Malaysia since the 1980s [1]. Nonetheless, the average wind speed in Malaysia is low, thus creating a great challenge for commercial wind power generation. Concerning this issue, appropriate wind turbine generators (WTGs) that can cope with such wind conditions should be chosen. Micro-type WTG seems to be the best option and will be applied in this study. RE related issues in Malaysia are managed by the Sustainable Energy Development Authority (SEDA) including a monitor and review of the Feed-in Tariff (FiT) system [2].

Furthermore, the main drawback of wind power is its fluctuating and intermittent characteristics, which might drive serious technical issues i.e. voltage instability and frequency control problems if a large amount of wind power penetrates into the existing grid [3, 4]. Therefore, these problems should be resolved before (if possible) a large capacity of wind power is integrated into the Malaysian National Grid. Battery storage is reported to be one of the potential solutions to mitigate fluctuation and intermittency [5]. By using a battery, steady-state wind power can be produced and dispatched, hence capable of reducing negative impacts on the grid. These hybrid systems, however, entail an effective strategy to achieve the best possible outcomes.

The aim of this paper is to propose a dispatch strategy for a wind farm equipped with a battery to supply wind power to the grid with minimal fluctuation. The strategy's main components will be an approach to determine optimum reference dispatch power,  $P_{ref}$  based on the forecasted wind speed plus, the battery control approach for safety operation to reduce the life cycle degradation. A case study is conducted using the monthly mean wind speed data measured at Mersing weather station in 2009. The performance of the proposed dispatch scheme is observed via several simulation studies.

The remainder of the paper is organized as follows. Section 2 presents system descriptions related to the whole study. The proposed dispatch strategy is discussed in detail in Section 3. In Section 4, case study and results are discussed followed by the conclusion in Section 5.

## 2. System Description

This section summarizes the mathematical models of the WTG and battery systems. First, the selected WTG is introduced followed by its mathematical representation in estimating the output power. Then, the battery model is described in the context of its state-of-charge ( $SOC$ ) which is significant in these studies.

### 2.1. 300 W Wind Turbine Generators

In wind farm development, proper selection of WTGs are crucial. In this paper, based upon monthly mean wind speed data of Mersing station obtained from [7], 300 W WTG available in the market namely the *Infiniti 300* (Figure 1) will be considered. In the datasheet, the manufacturer also has provided the amount of power the WTG can produce at a particular wind speed [8]. Therefore, the power curve as shown in Figure 2 can be plotted accordingly. All the important parameters of the *Infiniti 300* are presented in Table 1. As shown in the table, this WTG will start to rotate and generate power at low wind speed which is at 2.5 m/s (also referred to as cut-in wind speed). Otherwise, the output power of WTG can also be estimated using the following formula [6]

$$P_{wind} = 0.5\rho\pi R^2 v_w^3 C_p(\lambda, \theta) \quad (1)$$

where  $\rho$  denotes the air density,  $R$  is the rotor radius,  $v_w$  is the wind speed in m/s and  $C_p(\lambda, \theta)$  is the WTG power coefficient as a function of  $\lambda$  and  $\theta$ , which are respectively the tip-speed ratio and the blade pitch angle.

Table 1. WTG parameters

Rated power	300 W
Cut-in wind speed	2.5 m/s
Rated wind speed	12 m/s
Cut-out wind speed	20 m/s
Rotor diameter	1.12 m

### 2.2. Battery Dynamic Model

It is well-known that battery storage is very useful in reducing power fluctuation. Typically, a commercial battery is built-in with a battery management system to ensure the battery operates in a safe range for prolonging battery lifetime. Its major function is to control the  $SOC$ , whereby in this study the safe range is set in between 20% ( $SOC_{min}$ ) to 100% ( $SOC_{max}$ ).  $SOC$  can be estimated using coulomb counting method such as follows [4]:



Figure 1. The *Infiniti 300* [2]

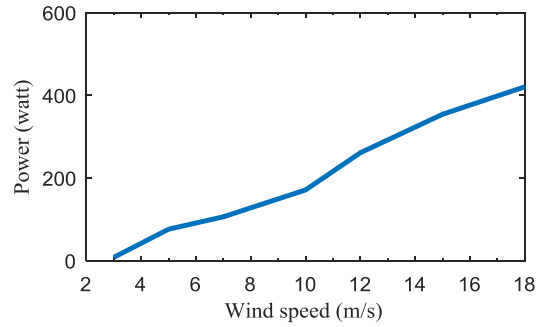


Figure 2. Power Curve for the *Infiniti 300*

$$SOC = SOC_0 + \eta_{eff} \int \frac{I_{batt}}{Q_{batt}} \quad (2)$$

where  $SOC_0$ ,  $\eta_{eff}$  and  $I_{batt}$  refer to the  $SOC$  initial value, coulombic efficiency and battery current respectively. Considering a battery with specific rated power  $P_{batt(rated)}$  that could supply for  $T_{batt}$  hour of duration has been installed. Therefore, its capacity,  $Q_{batt}$  can be represented as

$$Q_{batt} = I_{batt(rated)} \times T_{batt} \quad (3)$$

where the rated battery current,  $I_{batt(rated)}$  is obtained from  $P_{batt(rated)} / V_{batt(rated)}$ . The battery parameters are listed in Table 2.

Table 2. Battery Parameters

Rated power	1500 W
Rated voltage	24 V
Rated current	62.5 A
Capacity	125 Ah
$\eta_{eff}$	0.92
$T_{batt}$	2 h

## 3. Proposed Dispatch Strategy

Figure 3 illustrates the configuration of wind farm equipped with battery connected to the grid in the proposed manner. The main objective is to send wind power to the grid with less fluctuation while attempting to achieve a certain target level of dispatch power with the aid of battery. In the meantime, the battery  $SOC$  constraints are also to be satisfied.

### 3.1. Monthly Target Dispatch Power

Plenty of methods have been recommended in the literature for dispatch power scheduling such as an *average*, *min-max* and *optimal method* to name a few [10, 11, 12]. It should be mentioned that these methods require wind forecast data for scheduling. Based on the forecasted wind speed, wind power can be forecasted accordingly. The *average method* is practiced in this study, whereby  $P_{ref}$  for every interval is determined by averaging the forecasted wind power for the month (consider forecasting at least a month ahead). In this case, since monthly mean wind speed data is available,  $P_{ref}$  for a single WTG can be obtained directly from the power curve in Figure 2. Meaning that,  $P_{ref}$  will be altered monthly relevant to the forecasted mean wind speed data for that particular month.  $P_{ref}$  for the whole year of study is shown in Figure 6.

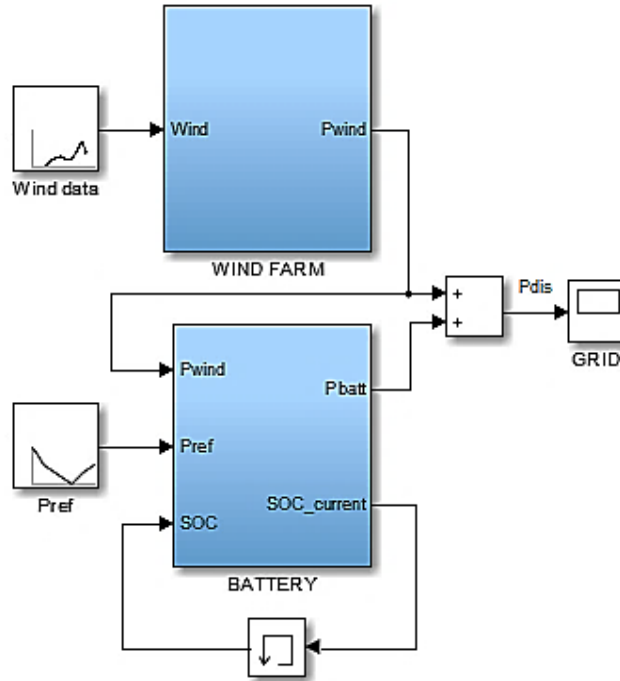


Figure 3. Block-diagram overview of the proposed dispatch scheme

### 3.2. SOC Feedback Control Approach

As can be seen in Figure 3, *SOC* feedback control approach is suggested in the battery controller. This is to ensure the battery is only effective within *SOC* safe operating region. In addition, the controller inputs also include  $P_{wind}$  and  $P_{ref}$ . Figure 4 demonstrates in detail the proposed battery regulation. Assuming  $P_{wind}$  is measurable, hence, the required battery power,  $P_{batt}$  can be calculated from

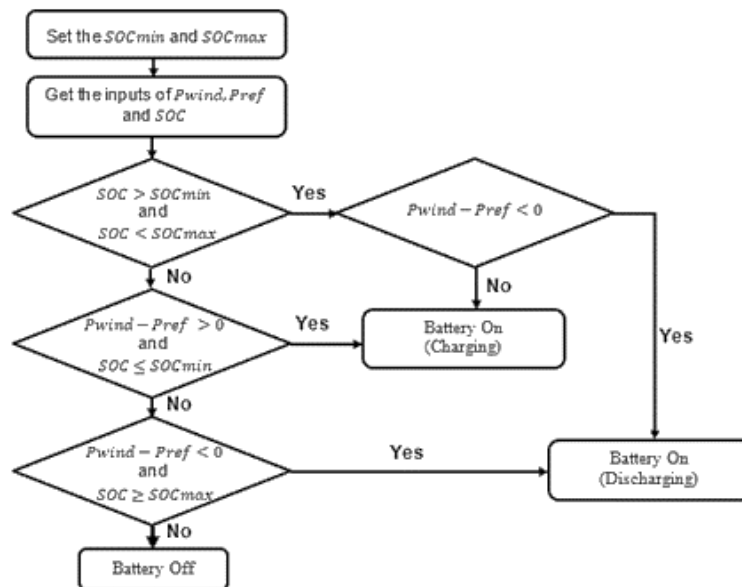


Figure 4. Battery control approach

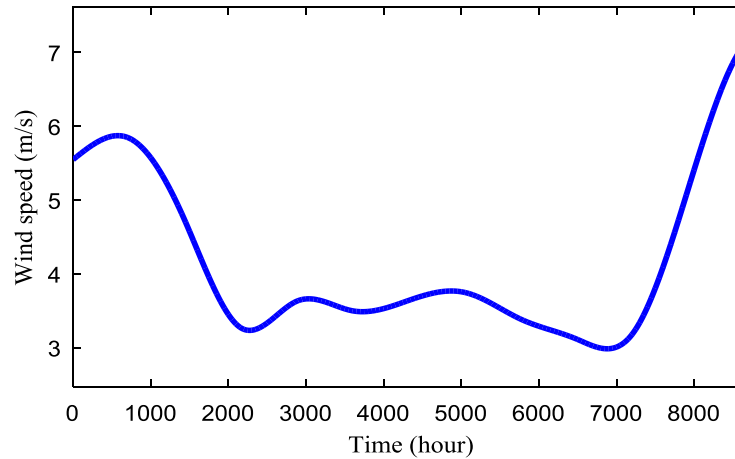
$$P_{batt} = P_{wind} - P_{ref} \quad (4)$$

In practice,  $I_{batt}$  can be controlled to get the desired  $P_{batt}$ . In this case,  $V_{batt}$  is assumed constant at  $V_{batt(rated)}$  thereby voltage drop is neglected. Thus,  $I_{batt}$  that will be adjusting the *SOC* dynamic in equation (2) is directly calculated from  $P_{batt} / V_{batt}$ . Positive  $P_{batt}$  and the corresponding  $I_{batt}$  reflect charging whereas negative for discharging. In the end, the total active power,  $P_{dis}$  delivered to the grid is equal to

$$P_{dis} = P_{wind} + P_{batt} \quad (5)$$

**Table 3.** Monthly mean wind speed data and power reference for a year

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$v_w$ (m/s)	5.55	5.84	4.72	3.27	3.63	3.50	3.64	3.75	3.39	3.12	3.18	5.14
$P_{ref}$ (watt)	872.6	918.7	686.9	184.9	322.3	273.2	326	366.9	231.1	126.7	150	792.3

**Figure 5.** Wind speed profile for a year

## 4. Case Study and Simulation Results

To demonstrate the performance of the proposed dispatch scheme, simulation studies are performed in MATLAB/Simulink. Real wind data with a 1-month resolution measured at Mersing is used [7]. Then, the data has been spline interpolated into a time-series data-set as displayed in Figure 5. It should be expected that the real wind data will not be as smooth as the graph. It shows that during early and end of the year, the wind flows at high speed, but quite low in the middle of the year. These significant variations happened due to the two monsoon wind seasons experienced by Malaysia. The simulation studies are conducted for 8640 hours to simulate a year period of wind data. Let's consider the wind farm contains ten micro-WTGs. With the consideration that all the installed WTGs are identical, their specifications as described in Section 2. In the meantime, wind speed that hit each turbine is also assumed to be equal whereby wake effect is ignored. Therefore, the total  $P_{ref}$  at every interval for that wind farm can be simply multiplied by ten. That means the total capacity of wind farm is 3000 W. Both wind speed data and the corresponding  $P_{ref}$  are tabulated in Table 3.

### 4.1. Wind Power Dispatched to the Grid

The wind power is allegedly dispatchable such as the other conventional generators if a certain amount of power could be delivered to the grid as requested by the transmission operator system in fulfilling the demand. In this paper,  $P_{ref}$  is referred to as the power demand that can be updated monthly. Thus, by following  $P_{ref}$  as close as possible, the wind power dispatchability is improved. All the associated powers are plotted in Figure 6. The blue line represents the

total power dispatched to the grid. It demonstrates that assisted by the battery, steady-state power is achieved at the specific  $P_{ref}$  for most of the intervals. In the other words, the power fluctuation has been minimized as well as its the dispatchability.  $P_{wind}$  generated by the wind farm is plotted in the red line. Obviously shown that by averaging the wind power of a particular interval, an optimum  $P_{ref}$  is obtained, hence only a small volume of  $P_{batt}$  is needed to compensate for the power mismatch. The power mismatch, so-called  $\Delta P$  is computed from  $\Delta P = P_{dis} - P_{ref}$ .  $\Delta P$  in the figure is plotted in the green dotted line. Positive value denotes extra power is delivered to the grid, whilst the negative value means less power is delivered to the grid; as compared to  $P_{ref}$ . This  $\Delta P$  is produced due to the updated battery  $SOC$  is either at the minimum or maximum level. Consequently, the battery is turned off to protect from over-charging or over-discharging.

Figure 7 reveals the amount of  $P_{batt}$  used to compensate for the power deviation in order to track  $P_{ref}$ . Positive  $P_{batt}$  verifies that the battery is charged and vice versa for the negative value. It is observed that large  $P_{batt}$  is used twice throughout the simulation studies which is around early and end of the year. This is because, during those two periods, the big change of  $P_{ref}$  occurs due to the drastic change in wind speed flow. The  $SOC$  response is depicted in Figure 8. It is clearly exposed that the battery only operates whenever  $SOC$  is within the range (20% to 100%) as per set. There are a few times where the battery is off so as to satisfy those constraints such as during the starting period. It happens when the  $SOC$  is already at the highest level, yet charging activity is demanded due to  $P_{ref}$  is lower than  $P_{wind}$ . For that reason, the battery has no option but must be off to avoid overcharging. As aforementioned, these phenomena have generated  $\Delta P$  whereby  $P_{ref}$  cannot be fully attained.

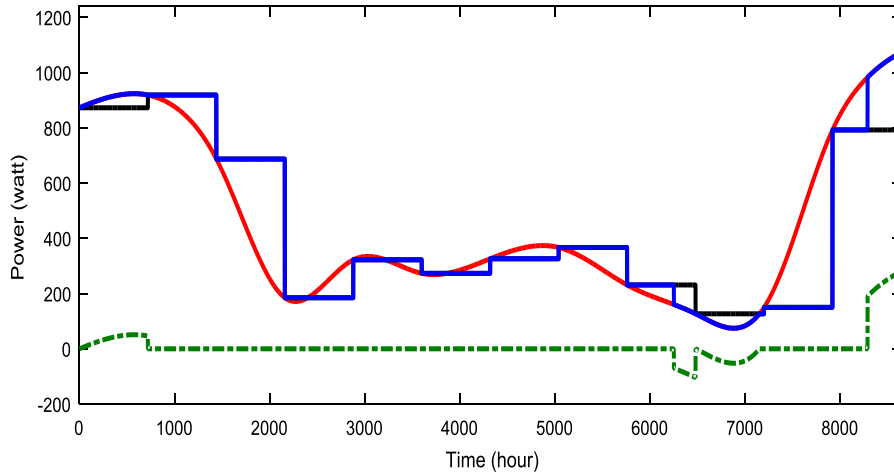


Figure 6.  $P_{wind}$  (red),  $P_{ref}$  (black),  $P_{dis}$  (blue) and  $\Delta P$  (dotted green)

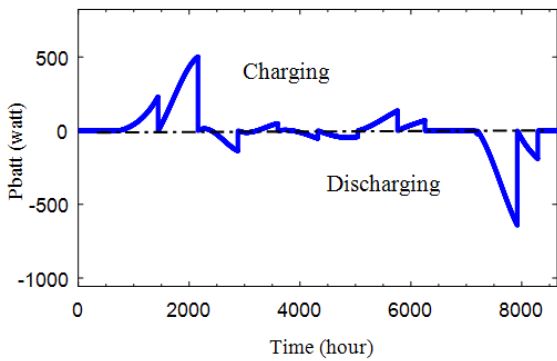


Figure 7.  $P_{batt}$  used during charging and discharging

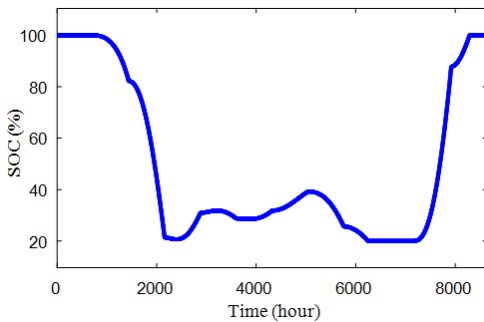


Figure 8. Battery SOC profile

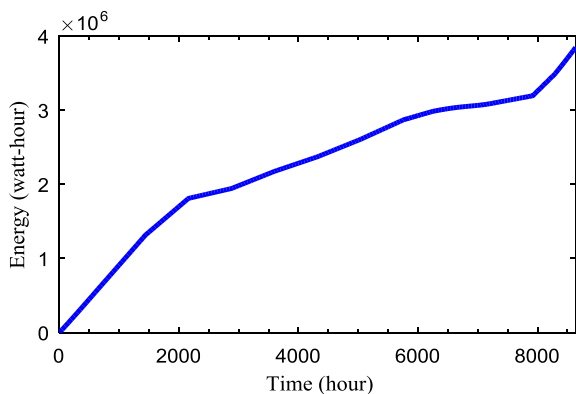


Figure 9. Energy dispatched to the grid

Finally, the total energy dispatched to the grid over the year is summed up and plotted in Figure 9. Approximately 3.85 MWh has been produced by the ten micro-WTG in the windfarm supported by the battery with the available wind speed at Mersing.

#### 4.2. Estimation of Payback Period

There are numerous ways to calculate an economic value for a certain project such as with a simple payback (SP), net present value (NPV) and internal rate of return (IRR) analysis [13]. In this work, the most common way, an SP (also called payback period) analysis is conducted using the following formula [14]

$$SP = \frac{\text{total capital expenditure}}{\text{total revenue}} \quad (6)$$

SP defines the time required to recover the amount of investment. As for now, Malaysia has not yet developed any wind farm because of the wind speed limitation, there is no capital expenditure (CAPEX) has been recorded in any publication that can be referred to. Thus, information from [15] is taken where the author has claimed that CAPEX for a small-scale wind farm in Malaysia is around RM12,500/kW. This assumption is made based upon the cost data taken from the invoices by the manufacturers. Meanwhile, the battery price is estimated at \$685.5/kWh (regardless of the installation cost) which is around RM2875/kWh. As referred in Table 2, a 3 kWh battery is utilized in this system.

As a result, the total CAPEX involved in the development of this project is calculated as  $(3 \text{ kW} \times 12,500 / 1000) + (3 \text{ kWh} \times 2,875 / 1000) = \text{RM}46,125$ . Based on the latest rates effective in January 2019, the rate (RM per kWh) for solar PV that is installed less than 4 kW is RM0.6014. Here, such price is used with the assumption that similar consideration will be applied to wind energy in the future. Then, the total revenue generated on a yearly basis pertinent to the simulation results can be computed from  $3.85 \text{ MWh} \times 0.6014 / 1000 = \text{RM}2,315$ . With that information, the SP hence can be predicted using equation (6) that is  $\text{RM}46,125 / \text{RM}2,315 = 20$  years.

## 5. Conclusions

In this paper, a dispatch strategy is proposed for a wind farm attached with a battery consists of ten micro-WTGs that suit the Malaysia wind condition. The aim of the strategy is to reduce wind power fluctuation dispatched to the grid while achieving  $P_{ref}$  that is monthly altered according to wind forecast. Meanwhile, battery safe operation is concerned about satisfying its  $SOC$  constraints. The simulation results verify that the proposed scheme successfully reduces the fluctuation and achieves  $P_{ref}$  for most of the intervals. Only some power mismatches fail to be compensated in fulfilling the battery  $SOC$ . From the SP analysis, around 20 years of time are needed to recover the project expenditure, which is unappealing to the investors. Nevertheless, the rapid advancement of micro-WTG technology in the market promises a potential enhancement of wind power harvesting in Malaysia, although at low wind speed. Competition among manufacturers in addition, possibly reduces the upcoming cost of wind farm development hence will reduce the payback period.

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