Dynamic simulation of a hybrid PV/Wind/Diesel system using power factory

Z R Renaldhy¹, A R Hutajulu¹, F Husnayain¹², D R Aryani¹², and A R utomo¹²*
¹Department of Electrical Engineering, Universitas Indonesia, Depok, Indonesia
²Electric Power and Energy Studies (EPES), Department of Electrical Engineering, Universitas Indonesia, Depok, Indonesia

E-mail: arutomo@eng.ui.ac.id

Abstract. Economic growth is one factors driving the need for expansion of the electricity system. However, power systems in some isolated areas are found to be unreliable because of some issues such as the transportation of components of the power system and fuel. The potential of local renewable energies can be the alternative for the development of power plants in these areas. However, most renewable energy sources produce relatively unstable voltage and power due to fluctuating primary energy sources conditions. This study proposes a hybrid generation system that utilizes the potential of local RES such as a PV system and a wind turbine generator, combined with existing diesel generators and equipped with a battery energy storage system. Simulations are carried out to observe and study the dynamic response of each component in response to the system frequency using PowerFactory software. The result shows the proposed hybrid system still operate well and stably due to the dynamic performance and coordination control between diesel generators and the battery energy storage system.

1. Introduction

Nowadays, most power generations are using fossil fuels as their primary energy sources, which the availability is getting depleting as well as contributing to the largest levels of air pollution [1]. Moreover, there are some challenges in developing power system in isolated areas particularly in transporting some power system components and fuel from main islands. Thus, the utilization of local renewable energy sources (RES) is considered to be suitable to overcome those issues [2].

Photovoltaic (PV) system and wind turbine (WT) generators are RESs that are getting more to be implemented lately. However, the primary energy sources such as solar irradiation and wind speed have intermittent characteristic which leads to instability in the electric system [3]. Several RES power output issues have been researched, such as the WT output fluctuation which causes instability in the system so a proper converter controller is proposed [4]. Another study shows the fluctuating output of a hybrid PV/WT system has negative impact on the power quality and system stability, and a battery energy storage system (BESS) is used to maintain the system [5],[6]. Control strategies for PV, WT, and BESS converters and diesel generator (DG) controller are designed to improve the system stability [7],[8].

This paper studies the dynamic performance of PV, WT, diesel generators (DG), and BESS controllers in a hybrid system. This simulation is conducted using PowerFactory to see the impact of frequency on power outputs of PV, WT, DGs and BESS.
The rest of the paper is organized as follows. Chapter one describes the background of this study. Chapter two presents the methodology of the research, afterwards, chapter three contains the simulation results and the analysis. Lastly, chapter four concludes the presented result.

2. Methodology

2.1 System Configuration

Figure 1. PV-Diesel-Battery-Wind Hybrid System configuration

Figure 1 shows the system configuration where DGs, PV, WT, and BESS are connected to bus 0.4 kV and all loads are connected to bus 20 kV. The system has a 450 kW PV power plant, a 1 MW WT generator, a 2 MWh BESS, and 4 MW DGs, while the total load is 4.11 MW.

2.2 The system dynamic performance

The increased loading causes the generator output power to be less than the input power from the mechanical generator that spin the prime mover. This causes kinetic energy deficiencies on the generator and quickly reduces the frequency [9]. The generator becomes unsynchronized as the synchronized angle between the rotor and the stator increases until it exceeds its clearance. As a result, the generator becomes unstable [10]. Disruptions will disturb the transfer of power generator to load. This will change the synchronized angle between the rotor and the stator[11]. The generator becomes unstable. This motion is described in the following swing equation, used for analyzing the transient stability [12].

\[
\frac{2H}{\omega_e} \frac{d^2 \delta}{dt^2} = P_m(u) - P_e(u)
\]

\(P_m\) and \(P_e\) are the per-unit mechanical and electrical power, \(\delta\) is rotor angle, while \(H\) is per unit inertia constant. In the case that the rotor locks back into synchronous speed after this oscillatory period, the generator will remain stable.

2.3 Controller of each component

Figure 2 - Figure 4 show BESS, PV, and DGs control blocks, while control parameters and configurations are displayed in Table 1-Table 3. These controllers are the typical models provided in global library of PowerFactory.
**Figure 2.** BESS control block

**Figure 3.** PV control block

**Figure 4.** The Automatic Generation Control (AGC) block

**Table 1.** The parameters of battery cells and charge control

| Parameters                              | Values  |
|-----------------------------------------|---------|
| Initial SOC                            | 0.25    |
| Capacity per cell [Ah]                  | 80      |
| Voltage of empty cell [V]               | 12      |
| Voltage of full cell [V]                | 13.85   |
| Amount of parallel cells                | 60      |
| Amount of cells in row                  | 29      |
| Intern Resistance per cell [ohm]        | 0.001   |
| min charging current [pu]               | 0.05    |
| minimal SOC [pu]                        | 0.2     |
| maximal SOC [pu]                        | 1       |
| threshold for iq preference [pu]        | 0.9     |

**Table 2.** The parameters of PV array configuration

| Parameters                              | Values  |
|-----------------------------------------|---------|
| Open-circuit Voltage of Module[V]       | 37.4    |
| MPP Voltage of Module [V]               | 30.7    |
| MPP Current of Module [A]               | 8.15    |
| Short-circuit Current of Module [A]     | 8.63    |
| Temperature correction factor (voltage) [1/K] | 0.0039 |
| Temperature correction factor (current) [1/k] | 0.0004 |
| SerialModules Number                    | 20      |
| ParallelModules Number                  | 9       |
| Time Constant of Module [s]             | 0       |

**Table 3.** The parameters of AGC

| Parameters                              | Values  |
|-----------------------------------------|---------|
| K Actuator Gain [pu/pu]                 | 9       |
| T4 Actuator time constant [s]           | 1       |
| T5 Actuator time constant [s]           | 0.002   |
| T6 Actuator time constant [s]           | 0.015   |
| TD Combustion Delay [s]                 | 0.001   |
| Droop [pu]                              | 0.02    |
| TE Time const. Power fdbk [s]           | 0.5     |
| T1 control box time constant [s]        | 0.018   |
| T2 control box time constant [s]        | 0.0001  |
| T3 control box time constant [s]        | 10      |
| Droop _Control (0=Throttle fdbk. 1=Elec. Power fdbk) | 0   |
| Prime Mover Rated Power [MW]            | 0.216   |
| Min. Throttle [pu]                      | 0       |
| Max. Throttle [pu]                      | 1       |
2.4 Coordination of diesel generators and BESS

As RES, PV and WT generate power according to the availability of primary energy sources and both are independent to the system frequency. Meanwhile, BESS and DGs operates according to the system frequency as follow:

- If the system frequency is decreasing, BESS will be in discharging mode until the SOC is 20%, then DGs increase their power output if the system still lacks power
- If the system frequency is increasing, BESS will be in charging mode until the SOC is 100%, then DGs decrease their power output if the excess power is still flowing in the system.

3. Simulation and result

3.1 Controller performance of each component

Figure 5 shows the response graph of a DG during the existence of 10% load step on the 5th second, which caused the frequency to decrease from initial point of 50 Hz. The AGCs respond the system frequency by raising DGs active power output. The frequency will enter a new steady state condition in 49.6 Hz when the power output from DGs reaches steady state point.

The same 10% load step condition is applied to a BESS at t=10s with the response is shown in Figure 6, causing the frequency to decrease from initial point of 50 Hz to a new steady state point of 49.9 Hz.

It is observed that BESS controller has faster response compared to the AGC of the diesel.

Figure 7 shows the response of each component in a hybrid DG/PV/Wind and BESS system when there is 10% load step on the 10th second. After the occurrence of load step, the BESS power output increment is larger compared to DG’s due to the fast response of BESS controller. The 10% load step reduces the frequency on the system, and the frequency returns to steady state condition after the DG and BESS reacts.
3.2. Controllers performance on the system

3.2.1. Scenario 1. Figure 8 shows the power flow in the system while Figure 9 and Figure 10 display the system frequency and BESS SOC respectively. Initially, system operated with frequency of 49.9 Hz. Suddenly, the 450 kWp PV is disconnected from the system on the 100th second. Since the BESS responds faster compared to AGCs, it discharges larger power of 329 kW, while the remaining demand is satisfied by DGs. The system frequency is maintained in 49.8 Hz. However, at the 360th second the BESS SOC reaches its minimum level of 20% so BESS stops discharging the power. AGCs of seven load follower DGs sense the power deficit on the system through the decrease of system frequency, so all DGs increases the power output with load sharing scheme to compensate the power deviation on the system, resulting system frequency safely operates in 49.53 Hz.

![Figure 8. Power output of diesel generators, PV, WT, and BESS in scenario 1](image)

![Figure 9. BESS SOC in scenario 1](image)

![Figure 10. System frequency in scenario 1](image)

3.2.2. Scenario 2. Figure 11 shows the power flow in the system while Figure 12 and Figure 13 display the system frequency and BESS SOC respectively. Initially, system frequency operated in 50 Hz. There is 776 kW excess power in the system which is charged by BESS. At 185th second, BESS SOC reaches its maximum level so BESS stops charging the power. The AGCs sense the frequency due to the excess power flowing in the system. To maintain power balance, The AGCs of seven DGs decreases the power output with a load sharing scheme, resulting system frequency safely operates in 50.4 Hz.

![Figure 11. Power output of diesel generators, PV, WT, and BESS in scenario 2](image)
4. Conclusion
This paper simulates the dynamic performance of PV, WT, DG, and BESS controllers. In addition, this paper proposes the coordination of BESS and DG AGCs when there are some transient events. According to simulation results, each controller performs well in responding dynamics on the system. The proper coordination among controllers can maintain the system to operate safely.

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