Effects of Solar and Wind Power Energy Sources Integration on Frequency Dynamics in Microgrid

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Abstract. The need for electricity that continues to increase requires increasing electricity generation capacity and building comparable transmission and distribution systems and a smarter system for dealing with increasingly complex forms of electricity production and consumption. Renewable energy, such as solar and wind, are ones of the solutions to increase electricity generation capacity but has problems with its intermittent and other grid related problems, which can be solved by using Power Electronic Interfaces (PEIs), i.e., Battery Energy Storage Systems or converter of renewable energy sources (RES), to keep the quality and stability of the power system. However, the increasing penetration rate of RES, which gather several different types of energy sources and generations system, in an electrical power system will make need a more complex system control. Objective of this research was to study the effects of RES integration on frequency dynamics in microgrid to further develop and increase its stability and quality by modeling and simulation using MATLAB/Simulink software.

1. Introduction

The growing need for electricity requires an increase in electricity generation capacity and the development of a comparable and smarter transmission and distribution system for dealing with increasingly complex forms of electricity production and consumption. Renewable energy as the trending solution, such as solar dan wind energy, has a problem with the continuity of its supply. Connecting them to a power system with its increasingly complex demand will pose a challenge to keep the stability and quality of the power system. One solution to this problem is the use of an Energy Storage System (ESS) that can respond to rapid changes in the electricity system network. ESS can be used both on the generation, transmission, distribution, or consumer side to provide a variety of services, overcome challenges and operational needs and potentially reduce costs [1]. One of the ESS is the Battery Energy Storage System (BESS) which is often used in conjunction with solar power plants. BESS can support the reliability of network operations by helping network operators respond to fluctuations in electricity supply generated by renewable energy resources, or disruptions in the network, such as loss of transmission lines or generating units. In addition, BESS can provide additional support services needed to maintain system reliability and support the transmission of electrical energy. BESS can be utilized in various ways to improve the reliability, durability, and efficiency of network operations. In particular, BESS can provide frequency and voltage regulation services to maintain system stability and quality with a very fast response.

BESS proved to be one of the most feasible solutions to a number of problems related to electricity grid management and control which showed an increase in variable power generation...
rates. Additional flexibility brought to the system by optimal BESS placement encourages the growth of the renewable energy share [2]. BESS can help to regulate lost energy production arising from renewable energy [3, 4]. Storage system performance depends on each technical characteristic, such as storage capacity, discharge rate, cycle efficiency, lifetime, energy and power density and cost [3, 5]. The contribution of BESS in terms of the stability and flexibility of the electricity network has been studied by considering several aspects. One factor to consider before installing BESS is its location in the electrical system [6]. The optimal positioning of BESS will minimize the need for investment in the grid and also optimizes its efficient use from the standpoint of reliability, safety, and operation of the system [5-7]. However, this does not mean that network upgrades are no longer needed. In fact, the integration of energy storage systems alone may not be enough to provide the reliability and flexibility needed in the system [5]. Therefore, the comparison of investments and the associated costs of the two options is very important, because benefit analysis that considers both solutions can be profitable [7, 8].

However, a new frequency instability phenomenon that has never been observed in conventional Synchronous Generator-dominated systems, i.e., the second frequency drop (SFD), may occur as Power Electronic Interfaces (PEIs), i.e., BESS or converter of renewable energy sources, restore their operating states. After providing a certain duration of temporary frequency support, PEIs need to restore their rotor speed or bus voltage to the initial operating states and maintain their own operation stability. To achieve that, PEIs typically implement a deliberate reduction of their electromagnetic output power, which may cause another frequency event. Once large number of PEIs are involved in complex switch-on/-off of the participation of frequency responses, the system may suffer a series of significant SFDs [9].

Hadjidemetriou et. al. in [10] has investigated the operation of a realistic dynamic power system with high penetration of RES to investigate how an integrated RES can beneficially affect the operation of the power system in terms of voltage and frequency stability. Casado-Machado et.al has developed Simplified Models for Frequency Studies in Electrical Power Systems in [11], although stated that the detailed approach should not be replaced by the simplified approach for primary frequency studies in electrical systems with several nodes as it produces lack of precision [12-23].

Therefor in order to develop and increase microgrid stability and quality and to overcome the effects of renewable energy sources penetration to power system dynamics by using BESS, it is important to study their effects. This research was preliminary study and will focus on the study of the effects of RES integration on frequency dynamics in microgrid by modeling and simulation using MATLAB/Simulink software.

The rest of paper is organized as follow. Section 2 introduces the simulation methods and its scenarios. Simulation results is presented in Section 3. Section 4 concludes the paper.

2. Simulation methods and scenarios

2.1. Test system

This study simulated frequency dynamics of microgrid using modified IEEE 9-bus system for 24 hours (86,400 seconds) simulation in Matlab/Simulink Software for each scenario, where there are three power generation units and three load systems as seen in figure 1. The power generation units used were a diesel, solar and wind power generation units in GEN 1, 2 and 3 respectively. The load system used were 2 static and 1 variable load in LOAD A, B and C respectively.

2.2. Load systems

Maximum total load used in this study was about 25.5 MW. Static load used in Load A and B were 5 MW for each of them and variable use in Load C was a load system with a maximum of 15.5 MW. Load profile of total power consumption, Load A, B and C can be seen in figure 2.
2.3. Power generation unit

Power Generation unit used was from matlab/simulink library or example. For Solar power generation unit, there were three irradiation profile used for solar power generation unit that can be seen in figure 3 a, b and c.

The irradiation profiles simulated three solar power intermittency scenarios, no intermittent, half-power intermittents and full-power intermittents which were simulated for 10 minutes in every 30 minutes with a maximum of 525 W/m². For wind power generation unit, wind profile used with a maximum speed 14.5 m/s can be seen in figure 4.

2.4. Simulation scenarios

Simulation in this study was carried out by doing several simulation scenarios with three load, three irradiations and one wind speed profiles for three power generation condition scenarios that can be seen in table 1.

| Type                  | Renewable Energy Sources (RES) Percentages (%) | Maximum Power Generation (MW) |
|-----------------------|-----------------------------------------------|--------------------------------|
|                       | 25                        | 50                | 75                |                                  |
| Solar Power Generation| 1.87                      | 8.25              | 14.62             |
| Wind Power Generation | 4.5                       | 4.5               | 4.5               |
| Dieasel Power Generation| 19.13                    | 12.75             | 6.38              |
3. Simulation results

Maximum frequency dynamics due to solar power energy sources intermittent from simulation 1-9 can be seen in Table 2. Increase of percentages in renewable energy sources power generation that supplied the microgrid, in this case solar energy sources, increased maximum frequency drop and increase percentages.

Table 2: Maximum frequency dynamics due to solar energy source

| Irradiation Profile          | Renewable Energy Sources (RES) Percentages (%) | Solar Energy Sources Percentages (%) | Maximum Frequency Dynamics due to Solar Energy Source (%) |
|-----------------------------|-----------------------------------------------|-------------------------------------|----------------------------------------------------------|
|                             | 25  | 50  | 75  | 7.33 | 32.35 | 57.33 | Drop (-) | Increase (+) | Drop (-) | Increase (+) | Drop (-) | Increase (+) |
| no Intermittent             | 0   | 0   | 0   | 0    | 0    | 0     | 0        | 0         | 0        | 0        | 0        | 0        |
| half-power intermittent     | 0.10| 0.10| 0.62| 0.56  | 1.18  | 1.08  |          | 0         | 0        | 0        | 0        | 0        |
| full-power intermittent     | 0.20| 0.24| 1.30| 1.40  | 2.26  | 2.20  |          |           |          |          |          |          |

The increase of 25% solar energy sources (7.33% to 32.25%) increased maximum frequency drop and increase in half-power intermittent to 0.52% (0.1% to 0.62%) and 0.46% (0.1% to 0.56%) respectively and in full-power intermittent 0.9% (0.2% to 1.3%) and 1.16% (0.24% to 1.4%) respectively. Another increase of 25% solar energy sources (32.55% to 57.33%) increased maximum frequency drop and increase in half-power intermittent to 0.58% (0.62% to 1.18%) and
Figure 3: Load Irradiation profile (a) no intermittent (b) half-power intermittent (c) full-power intermittent

Figure 4: Wind Speed Profile for wind power generation unit
and 0.52% (0.56% to 1.08%) respectively and in full-power intermittent 0.96% (1.3% to 2.26%) and 0.8% (1.4% to 2.2%) respectively.

Maximum frequency dynamics due to wind power energy sources intermittent from simulation 1-9 can be seen in table 3. The frequency dynamics were around 0.7%. These due to there was no changes in wind energy generation. Increase of percentages in renewable energy sources power generation that supplied the microgrid, in this case solar energy sources, did not affect the maximum frequency drop and increase due to wind energy sources.

**Table 3:** Maximum frequency dynamics due to wind energy sources

| Irradiation Profile | Renewable Energy Sources (RES) Percentages (%) | Wind Energy Sources Percentage (%) | Maximum Frequency Dynamics due to Solar Energy Source (%) |
|---------------------|-----------------------------------------------|-----------------------------------|--------------------------------------------------------|
|                     | 25                | 50                | 75                | 17.65                        | Drop (-) | Increase (+) | Drop (-) | Increase (+) | Drop (-) | Increase (+) |
| no Intermittent     | -0.72             | 0.72              | -0.66             | 0.74             | -0.70             | 0.70            |
| half-power intermittent | -0.68           | 0.74              | -0.68             | 0.74             | -0.66             | 0.74            |
| full-power intermittent | -0.68           | 0.70              | -0.66             | 0.74             | -0.66             | 0.74            |

4. Conclusions
This study can be concluded that the increase of renewable energy sources, in this study was solar energy sources, increased frequency dynamics percentages in microgrid. The increase of 25% of renewable energy sources will increase the frequency dynamics percentage average to 0.52% in half-power intermittent and 0.96% in full-power intermittent of solar energy sources. Increase of percentages in solar energy sources and their intermittency did not affect the frequency dynamics due to wind energy sources.

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