Engineering Applications

https://publish.mersin.edu.tr/index.php/enap

e-ISSN 2979-9201

Effect of energy storage on power system stability

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Cite this study: Acar, A., & Kaygusuz, A. (2022). Effect of energy storage on power system stability. Engineering Applicaations, 1(1), 91-98

Keywords
Energy Storage
Power System Stability
Renewable Energy
Distributed Production
Smart Grid

Research Article
Received: 11.04.2022
Revised: 18.05.2022
Accepted: 25.05.2022
Published: 18.06.2022

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Abstract

Nowadays, the difference between the amount of energy produced and the amount of energy consumed is increasing. However, the resources of traditional energy production methods are gradually decreasing and cause environmental pollution. Limited resources lead us to renewable energy sources. On the other hand, production with renewable energy sources brings with it the changing global climate problem. The efficient, functional and continuous use of this energy is as important as the production of energy. However, systems based on renewable energy sources such as solar and wind cannot respond quickly and reliably to fluctuating demand as they have different generation profiles seasonally and during the day. This indicates that energy storage is an important issue. It is academically important to analyze the changes in the stability of power systems by integrating storage systems into power systems. In this study, it is aimed to minimize the production-consumption imbalance by integrating energy storage systems into smart grids and the response of system stability is analyzed. In practice, development studies were carried out on the basis of the MATLAB contents applied by Hadi Saadat. For this analysis, hypothetical generation and consumption systems have been created using the IEEE 14 bus power system.

1. Introduction

Energy, which is the key in our daily life, is very important socially and economically for all the countries of the world. The word energy brings to our memory primarily electrical energy, which is the cornerstone of our lives. Energy can be used in different forms in many parts of our lives, thanks to the various sources used during its production. The amount of energy we use in many areas of our lives such as energy lighting, heating, industry, communication and transportation is increasing and will continue to increase due to the increase in the world population and the continuous development of technology.

In parallel with this increase in demand, production also increases. Today, in order to respond to this increase, continuous and efficient energy is demanded in production areas. However, the depleted fossil fuel resource and the energy crises that may occur as a result, environmental pollution and global climate change lead us to the use of RES (Renewable Energy Resources). It is aimed to provide energy efficiency with the production made with RES. The place of renewable energy generation systems, whose source is sun and wind, is growing day by day in the global energy circle, as they do not harm the environment and do not run out of resources.

However, the fact that the seasonally fluctuating and intermittent power outputs of systems based on RES such as solar and wind during the day and the traditional grid infrastructure used today are not suitable for power systems based on RES leads us to find a solution to this problem. With the development of smart grid infrastructures, it is aimed that the use of ESS (Energy Storage Systems) will become widespread in order to ensure energy efficiency and continuity. Energy storage systems store the increased electricity at a certain time and give it back to the grid when needed.

Energy storage in smart grids [1];
• Having options to supply power for short or long periods,
• Can be used together with YEK,
• Intermediate gain,
• Increasing the quality of power,
• Additional benefits; rotating reserve, voltage regulation, frequency response,
• Load flow, correction of fluctuations in the load curve, correction of peak points,
• Flexible time use and safety.

It has many advantages such as. In addition, energy storage systems provide stability in frequency and voltage by reducing the difference between energy demand and generation capacity. Energy storage technologies (EDT) provide more stable power for large-scale manufacturers. Since this feature will solve the problems that may arise in the system on the basis of power, the use of energy storage systems instead of increasing the production systems in parallel with the increasing demand will protect it from material damages such as plant installation and operating costs. The widespread use of energy storage systems during the distribution of energy increases the efficiency by making the operation of the networks more efficient. There are several methods of storing excess energy demanded. As RES integration in conventional power systems becomes widespread, our need for energy storage methods for uninterrupted, efficient and safe power use will play a key role. It will also benefit financially as there will be no need to build new power plants [1].

Considering the increasing population, industrial growth and technological developments, we see that most of the investments and government incentives are aimed at meeting our increasing energy demand. All this shows that our efforts to obtain the uninterrupted energy we need for our social development and welfare through continuous and nature-friendly methods will increase gradually. With the widespread use of RES, it is predicted that the use of ESS will become widespread for our continuous and uninterrupted energy needs. This has made it an important issue to investigate the technical, cost, compatibility of the ESS with the power system infrastructure, and the effect on the stability of the system after they are integrated into the system.

2. Material and Method

Studies on the interaction of power systems based on renewable energy, which are increasing rapidly today, on system stability are academically important. In addition, the uncertain production situation of renewable energy and the need for an energy storage system in order to minimize the imbalance in the consumption-production band. When these issues are considered in their entirety, it is very important to transfer the production-consumption imbalances to the test systems correctly. In this direction, representative test systems with a certain scale have been created to investigate the effect of energy storage systems on system stability in cases where energy storage systems are integrated into existing power systems and renewable energy-based power systems. In this context,

IEEE's 14 bus test system, which is frequently used in the literature, was preferred and analyzes were made through the MATLAB program. The codes written by Hadi Saadat, which are accepted as the basis for stability analysis, were developed and analyzes were carried out. Newton-Raphson renewal method was used for stability analysis. While creating the scenarios, the energy storage system, solar generation unit and wind generation unit were integrated into the system, taking into account the load flow densities of the system. By creating possible fault scenarios in the system, the rotor angle, voltage and frequency stability of the system against these faults are analyzed. In terms of high efficiency, the charging and discharging time of the battery was chosen as 3 hours [2]. In determining the charging and discharging times of the energy storage system, the consumption profiles in the Production Capacity Projection report of the Turkish Energy Market Regulatory Authority covering the dates 2021-2025 are taken as a basis. Analyzes were performed with increasing iterations at intervals of 0.05.

2.1. Introducing the scenarios used in stability analysis

- **Current State**

The basic information about the current status of the 14-bus system is as follows14 bus power system: It consists of 15 transmission lines, 3 transformers, 5 machines and 11 loads [3]. The system is shown in Figure 1.

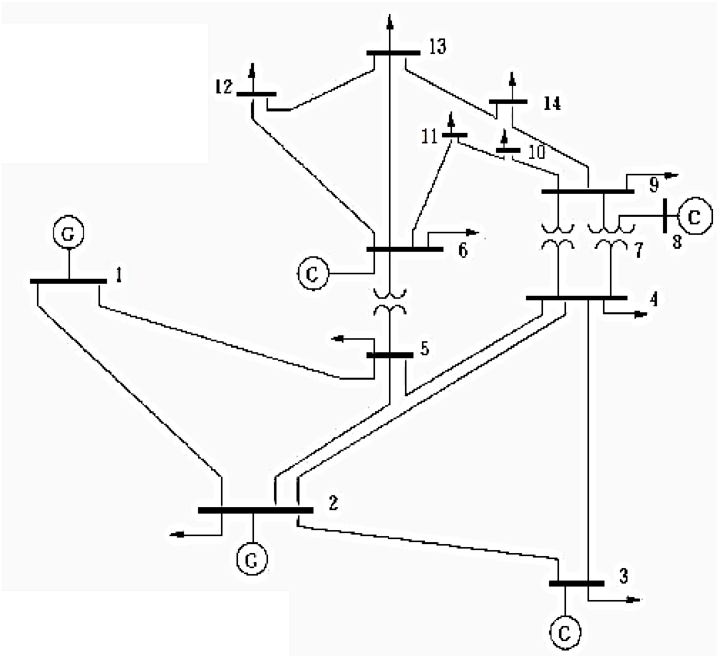

Figure 1. IEEE 14 bus system [4]

- **Scenario 1**

Considering the load densities of the buss, the busiest bus is the 2nd bus with a density value of 73%. Therefore, the energy storage system is integrated into the 2nd bus and faults are created close to the 2nd bus.

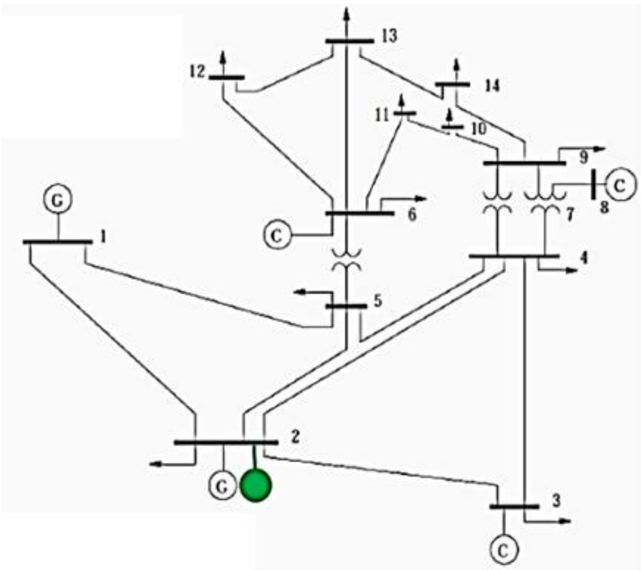

Figure 2. IEEE 14 bus system with added storage system (green circle)

The stability of the system in its current state is analyzed and the stability in the state after the energy storage system is added to the 2nd bus. The system is shown in Figure 2.

- **Scenario 2**

Considering the load density in the system, a solar generation unit was added to the 5th bus, and in the same case, an energy storage system was added to the 5th bus and the stability was analyzed. The system is shown in Figure 3.

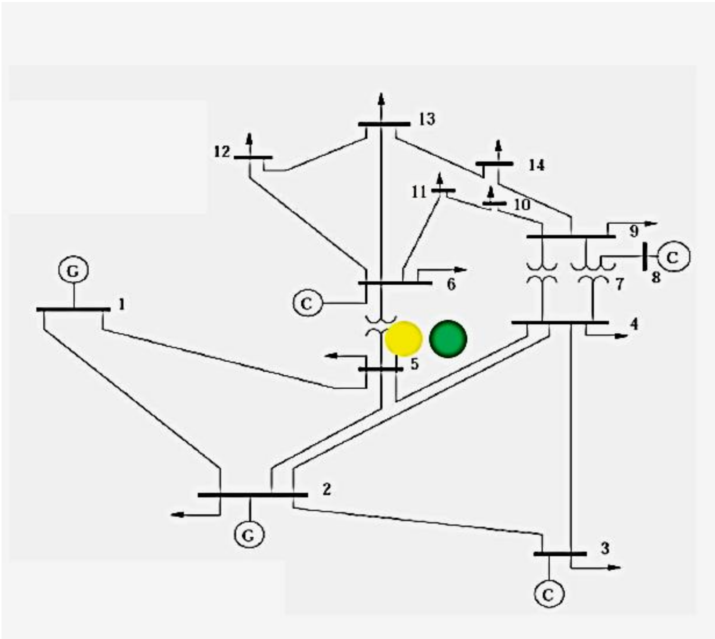

Figure 3. IEEE 14 bus system with added storage and solar system (yellow circle)

- **Scenario 3**

Considering the load density in the system, the current situation was accepted by adding a wind generation unit to the 5th bus, and in the same case, the stability was analyzed by adding an energy storage system to the 5th bus. The system is shown in Figure 4.

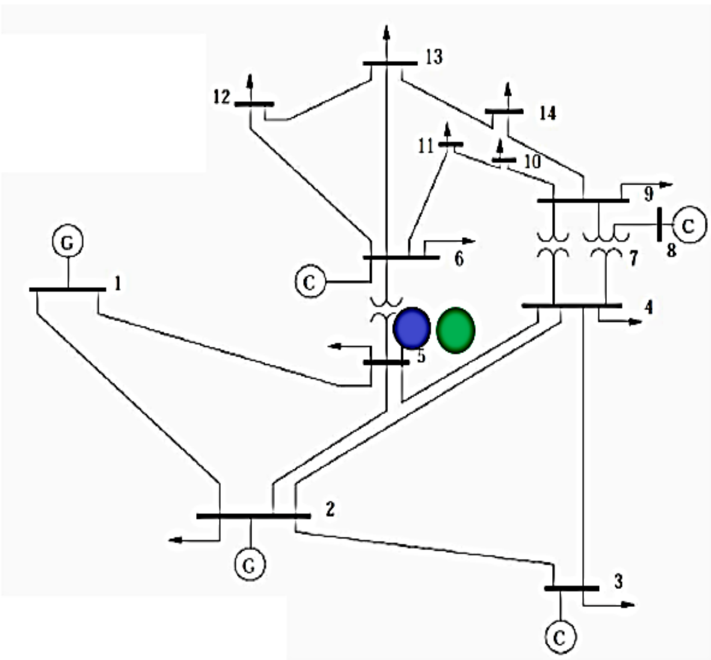

Figure 4. IEEE 14 bus system with added storage and wind system (blue circle)

- **Scenario 4**

By adding a wind generation unit to the 5th and 2nd buss and a solar generation unit to the 4th bus, it has been accepted as the current situation. In the current situation, stability has been analyzed by adding an energy storage system to the 4th bus. The test system is shown in Figure 5.

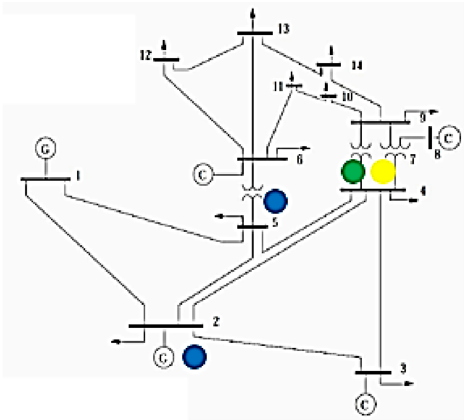

Figure 5. IEEE 14 bus system with added storage system (green circle), solar generation unit (yellow circle), wind generation unit (blue circle)

3. Results

• The results of the analyzes for scenario 1 are shown in Figure 6a, 6b.

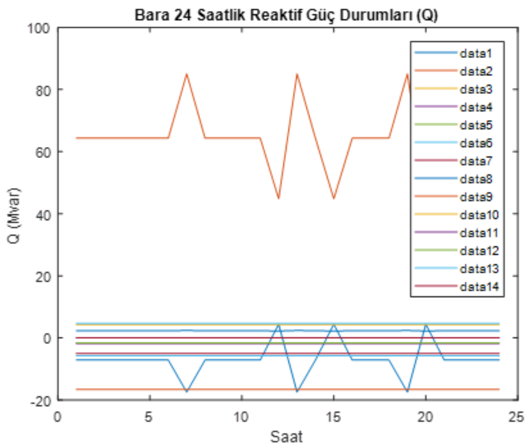

Figure 6 a) Reactive power state

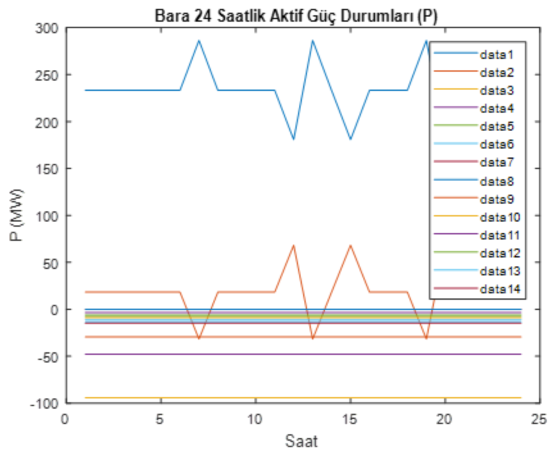

Figure 6 b) Active power state

In Figure 6a, it is seen that the most affected buses are the 2nd Bus (indicated in orange) and the 1st Bus (indicated in blue). In Figure 6b, the most affected buses are the 1st bus (shown in blue), the 2nd bus (shown in orange).

• Analysis results for scenario 2 are shown in Figure 7a, 7b.

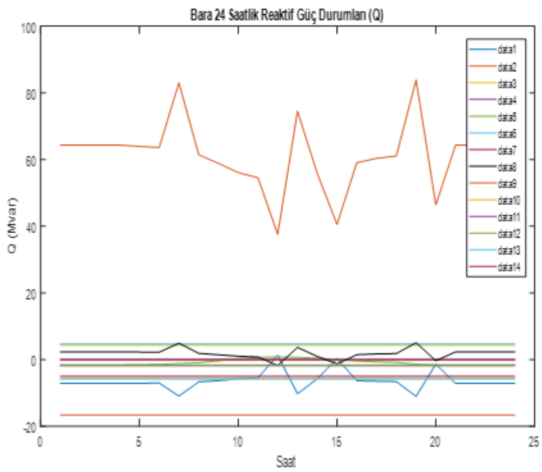

Figure 7 a) Reactive power state

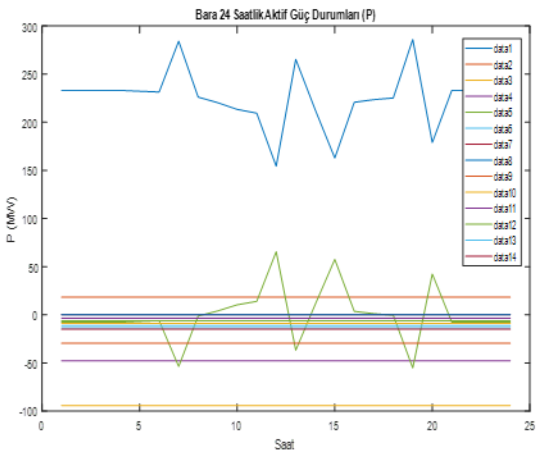

Figure 7 b) Active power state

In Figure 7a, it is seen that the most affected buses are the 2nd Bus (indicated in orange) and the 1st Bus (indicated in blue). In Figure 7b, the most affected buses are the 1st bus (shown in blue), the 5th bus (shown in green).

• The results of the analyzes for scenario 3 are shown in Figure 8a, 8b.

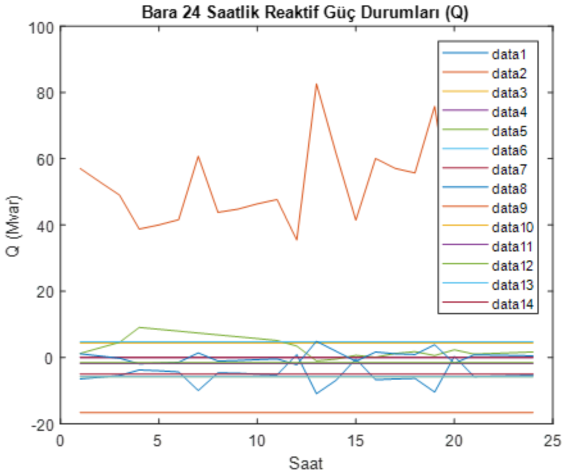

Figure 8 a) Reactive power state

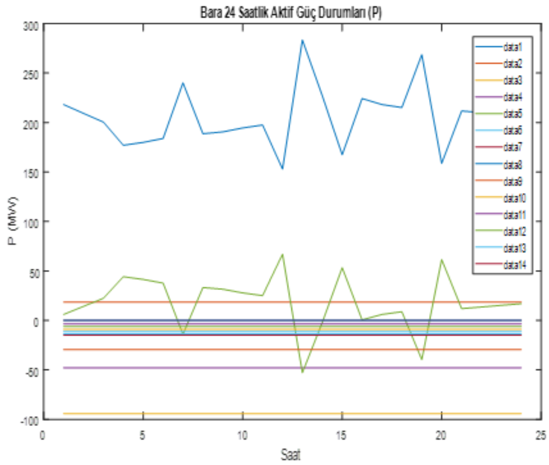

Figure 8 b) Active power state

In Figure 8a, it is seen that the most affected bus is the 2nd Bus (indicated in orange) and the 5th Bus (indicated in green), respectively. In Figure 8b, the most affected buses are the 1st bus (shown in blue), the 5th bus (shown in green).

• The results of the analyzes for scenario 4 are shown in Figure 9a, 9b.

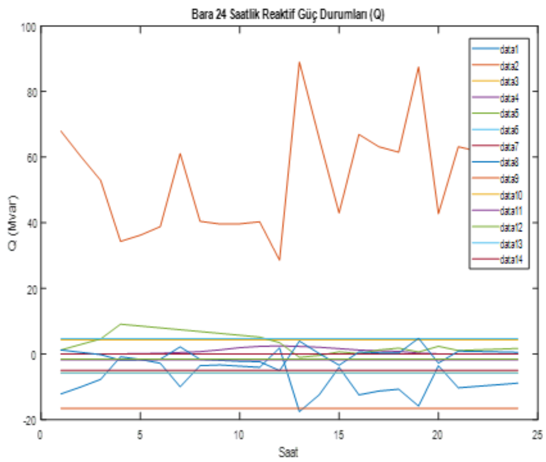

Figure 9 a) Reactive power state

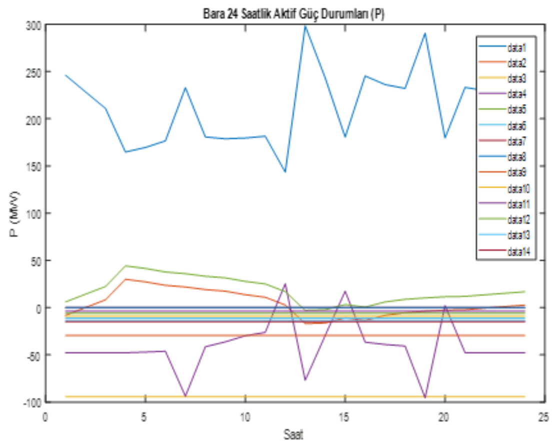

Figure 9 b) Active power state

In Figure 9a, it is seen that the most affected buss are Bus 2 (shown in orange) and Bus 1 (shown in blue), respectively. In Figure 9b, the most affected buses are the 1st bus (shown in blue), the 4th bus (shown in purple).

Analyzes were made by taking into account the hourly consumption-production values of Turkey. The stability of the system was examined with 0.05 second iteration. Since there is production at 07.00, 13.00 and 19.00, the energy storage system behaves like a load, that is, it is charging. Since consumption is high at 12:00, 15:00 and 20:00, the energy storage system acts as a generator. In other words, it provides extra power to the system.

When the data in Table 1 is examined, the energy storage system alone does not show a different result in case of failure in Scenario 1. However, when the energy storage system is used together with solar and wind generation units (Scenario 2, 3, 4), it has been observed that the stability of the system is longer when the storage system energizes the system.

Table 1. System instability times

Hour/Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario4	Current state
07.00	0.10	0.10	0.10	0.10	0.15
12.00	0.10	0.15	0.15	0.15	0.15
13.00	0.10	0.10	0.10	0.05	0.15
15.00	0.10	0.15	0.15	0.15	0.15
19.00	0.10	0.10	0.10	0.10	0.15
20.00	0.10	0.15	0.15	0.15	0.15

4. Discussion

In this study, it is aimed to see the changes in system stability with the integration of energy storage systems in power systems based on renewable energy sources. Since the energy obtained from smart grid integration renewable resources changes seasonally, annually, daily or even hourly, the importance of energy storage systems emerges to ensure the continuity of this energy.

Renewable energy sources have a great place in regulating the supply-demand imbalance of energy. Considering that the energy obtained from smart grid integration renewable resources changes seasonally, annually, daily or even hourly, the importance of energy storage systems emerges. However, it is of great importance to investigate the positive or negative consequences of energy storage systems when used together with existing power systems, smart grids, power systems based on renewable energy, academically and considering the future of our country in terms of energy production.

5. Conclusion

According to the results of the analysis, it is seen that the energy storage system has a positive effect on the stability of the system in case of a possible failure, while providing energy to the system, that is, in case of discharge. It has been observed that while storing energy from the system, that is, in the charging state, it behaves like a load and does not have a serious deterioration effect on the stability of the system.

It is predicted that the use of IEEE's 9, 30 and 39 bus power systems as a test system will also have positive effects on the literature.

In this study, the fact that test systems give different stability responses in different time periods during the day causes us to think that they will give different stability responses in real networks. For this purpose, smart technologies are included in the integration of distributed generation units and variable consumption units together with the energy storage system, and efforts to ensure the most suitable conditions continue without slowing down.

Acknowledgement

This study was partly presented in 2nd Advanced Engineering Days [5] on 16 March 2022.

Funding

This research received no external funding.

Author contributions

Ayşe Acar: Conceptualization, Methodology, Software, Visualization, **Asım Kaygusuz:** Data curation, Writing-Original draft preparation, Software, Validation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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