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Autonomous operation of microgrid and minimization of fault in case of failure in high-voltage lines

Yüksek gerilim hatlarındaki arızalarda mikroşebekenin otonom çalışması ve arızanın minimizasyonu

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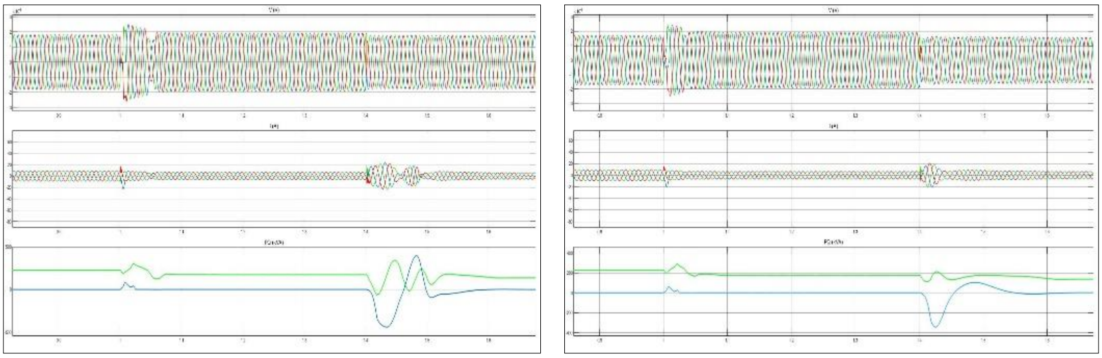
Autonomous Operation of Microgrid and Minimization of Fault in Case of Failure in High-Voltage Lines

Highlights

- *The algorithms that make autonomous maneuver management to the grid have been developed in case of symmetrical and asymmetrical faults in high voltage lines.*
- *The autonomous islanding mode operation has been carried out during the faults in order to prevent the consumers from being affected by faults.*
- *The energy management has been made according to the energy production amount of the distributed generation resources, when the designed microgrid started operating in islanding mode in the fault case.*
- *The SFCL has been designed to prevent damage to the loads and other components in the microgrid while the current characteristics of PV power supply change in case of faults during entry-exit to island mode.*

Graphical Abstract

Fault detection, autonomous maneuver management, division of loads into islands and Superconducting Fault Current Limiter (SFCL) have been studied against symmetrical and asymmetrical faults in high voltage lines.



(a) **(b)**

Figure. The simulation results a) without protection methods b) with protection methods

Aim

The aim is to minimize the damage on loads, grid and components of symmetrical and asymmetrical faults in high voltage lines

Design & Methodology

Simulation has been done in Matlab Simulink program with discrete time analysis method.

Originality

All protection methods have been integrated with smart management algorithms. In addition, the effectiveness of SFCL has been studied on the microgrid.

Findings

Simulation results have shown that the designed smart protection methods protect the grid and critical loads.

Conclusion

Symmetrical and asymmetrical faults were detected in the simulation, failure time was shortened and power fluctuations were largely suppressed with autonomous protection methods.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Autonomous Operation of Microgrid and Minimization of Fault in Case of Failure in High-Voltage Lines

Research Article /Araştırma Makalesi

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ABSTRACT

The manual reaction approach to faults is exhibited in conventional grid. Manual operations are slow in many cases and resulting in big fault and power cut. Turkey has experienced it by living on March 31, 2015. The switching to smart grids is inevitable in order to minimize human errors and avoid big failures. It is a solution to turn the appropriate zones back to the island mode, especially in case of emergency load shedding due to the basic frequency. However, large power fluctuations occur in the microgrids when switching to the island mode or connecting to the grid. Therefore, In Matlab / Simulink, a microgrid is designed that can operate in island mode in accordance with the smart grid structure to minimize the damage of symmetrical and asymmetrical of high voltage lines on loads, grid and its components in this study. Also the effects of Superconducting Fault Current Limiter (SFCL) have been studied to limit power fluctuations in the microgrid when switching to island mode and exit island mode. In addition, autonomous maneuver management has been carried out on the designed high voltage line to prevent faults resulting in long term power cut.

Keywords: Smart grid, microgrid, island mode, SFCL.

Yüksek Gerilim Hatlarındaki Arızalarda Mikroşebekenin Otonom Çalışması ve Arızanın Minimizasyonu

ÖZ

Konvansiyonel şebekelerde arızalara manuel reaksiyonel yaklaşım sergilenmektedir. Manuel oprasyonlar bir çok durumda yavaş kalmakta ve bunun sonucunda büyük arıza ve kesintiler meydana gelebilmektedir. Türkiye 31 Mart 2015 tarihinde bunu yaşayarak tecrübe etmiştir. İnsan kaynaklı hataların aza indirilmesi ve büyük arızaların yaşanmaması için akıllı şebekelere geçiş kaçınılmazdır. Özellikle temel frekansa bağlı acil yük atma durumlarında uygun bölgelerin ada moda döndürülmesi bir çözüm olarak karşımıza çıkmaktadır. Ancak, mikroşebekelerde ada moda geçerken veya şebekeye bağlanırken büyük güç dalgalanmaları gerçekleşmektedir. Bundan dolayı bu çalışmada, yüksek gerilim hatlarında meydana gelebilecek simetrik ve asimetrik arızaların yüklere ve iletim hatları ile bileşenlerine verebileceği zararları minimize etmek için Matlab/Simulink ortamında akıllı şebeke yapısına uygun olarak ada modlu çalışabilen bir mikroşebeke tasarlanmıştır. Ayrıca ada durumuna geçişte ve çıkışta mikroşebekedeki güç dalgalanmalarını sınırlandırmak için Superconducting Fault Current Limiter (SFCL) etkileri de incelenmiştir. Bununla beraber meydana gelen arızaların, uzun süreli kesintilere sebebiyet vermemesi için tasarlanan yüksek gerilim hattında otonom manevra yönetimi yapılmıştır.

Anahtar Kelimeler: Akıllı şebeke, mikroşebeke, ada mod, SFCL.

1. INTRODUCTION

Today, the increase in the frequency of faults is observed in power systems due to the increasing energy demand and the increase in the use of renewable energy sources and new power plants [1][2]. An autonomous smart grid architecture that can make quick and effective decisions should be designed in order to minimize the financial damage and to minimize the affect of failures on the routine life of people [3][4]. The Conventional distribution power systems have a radial structure in which power flows from the substation to the loads in one direction. Primarily, protection schemes should be created with correct protection coordination in order to transition to smart grid architecture. Protection schemes should isolate power systems as quickly as possible and provide maneuver management in case of failure [5] [6]. Another important matter in smart grid architecture is the strategy of protecting the grid and loads in case of failure by operating the zones in island mode. At this point, the concept of microgrid becomes important. Microgrid technology has been proposed to ensure efficient integration of distributed energy sources. While ensuring this, the microgrid needs to be controlled with an accurate energy management. It is very important to ensure the safety and stability of the microgrid under short circuit failures [7][8]. In other words, the power fluctuations that may occur during the transition of the microgrid to the

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island mode and the connection to the grid should be controlled. Microgrids are expected to switch stably between grid and island modes. The error signals can be different for each microgrid in these modes [9]. Despite extensive research on microgrid control and operation, microgrid specific relay has not been produced to date [10]. The SFCL is one of the methods used to control power fluctuations of micro grids in case of failure. In SFCL, there is no power loss during normal sensing time and provides rapid limiting operation within a quarter cycle without additional sensing device [11].

In order to minimize the damage caused by symmetrical and asymmetrical faults that may occur in power systems to loads, transmission lines and its components, the smart grid architecture that can operate in island mode with correct protection schemes is required. Here it is critical to suppress power surges at the micro grid-grid connection point.

1.1. Related Works

In recent years, many researchers have carried out important studies on failure analysis and precautions that can occur in power systems. Some of the important studies on grid protection schemes, microgrid and SFCL are presented below. In one study, a central specific strategy has been presented to protect medium voltage microgrids [12]. Another study presents a detailed review of the protection plans for renewable integrated power grids, including transmission, distribution and microgrid systems [13]. In another study, protection coordination has been studied to prevent possible failure [5]. In another study, ultra-high-speed pilot protection of transmission lines has been presented based on the directional comparison of transient energy [14]. In another study on protection schemes, a complementary fault identification scheme has been proposed for three-supply high-voltage transmission lines [15]. Digital impedance protection of transmission lines is a deficiency known not only as a principle but also as an application. In this study, a new application of wavelet-based artificial neural networks that overcome this shortcoming is presented [16]. In another study on SFCL, a stochastic approach is presented for evaluating transient recovery voltages induced along the Circuit Breaker poles of the simple test line equipped with SFCL [17].In a similar study, a method has been proposed that uses the voltage component as the effective parameter of the overcurrent protection relay to protect the power distribution system with SFCL [11]. In a study to analyze the effectiveness of SFCL, the applicability of different SFCLs in the voltage source converter based DC system according to the transient characteristics of the dc failure has been analyzed [18]. In another SFCL application, SFCL application has been performed in order to increase the performance of DC microgrids to which wind turbines have been connected under failure conditions [19]. In another similar study, resistant type SFCL application has been applied to protect the DC microgrid system [7].

1.2. Our Contibutions

It is anticipated that this designed autonomous smart grid operation can make the following contributions;

- Firstly the fault was identified in order to minimize the damages of symmetrical and asymmetrical faults that may occur in high voltage lines to the loads, transmission lines and its components. Subsequently, algorithms that will make autonomous maneuver management to the grid have been developed by isolating the fault point.
- It is envisaged to separate the loads into microgrids in order to prevent the consumers from being affected by faults. An autonomous island mode operation has been carried out during the faults.
- The energy management has been made according to the energy production amount of the distributed generation resources, when the designed micro grid starts operating in island mode in the faulier case.
- The SFCL has been designed to prevent damage to the loads and other components in the microgrid while the current characteristics of PV power supply change in case of faults during entry-exit to island mode.

The fault detection, autonomous maneuver management, operation of loads in island mode and intelligent energy management in microgrids have been realized by considering the designed system as a whole. Therefore, this system is a complete example of smart grid architecture and it is thought that it will inspire researchers.

2. DESIGN OF SYSTEM

The simulation studies in grid design provide great convenience and simplify the study of designers. The simulation studies increase the reliability of the system and enable the necessary optimizations to be made in advance. Thus the designed smart grid architecture is modeled and simulated in a matlab/simulink environment.

The ring distribution grid model is designed with 5 busbar in simulink model. In the model, 120 kV energy power supply was used. This voltage is reduced to 25 kV with transformers for distribution. The transmission line has been designed according to the π circuit model. In addition, a micro grid with 400 kW power level PV power supply has been designed and connected to the grid. Also, a symmetrical fault has been created between the two busbars (B4-B5) to see the network behavior. Finally, the necessary control software has been developed for isolating the fault area, maneuvering, switching to island mode and energy management, in the event of a fault. Whit that a suitable SFCL model has been developed, which is required to suppress the power oscillations of the microgrid both during failure and when entering and leaving the grid.

2.1. The Autonomous Maneuver Management Design

The switching under high voltage is called maneuvering. Generally, the maneuvering process is called opening the load, separating the contacts and safely grounding the system. In this study, when the fault occurs in the grid, the fault has been detected and the point where the fault occurred has been isolated from the line and the backup line has been activated. The maneuvering algorithm is given in Figure 1.

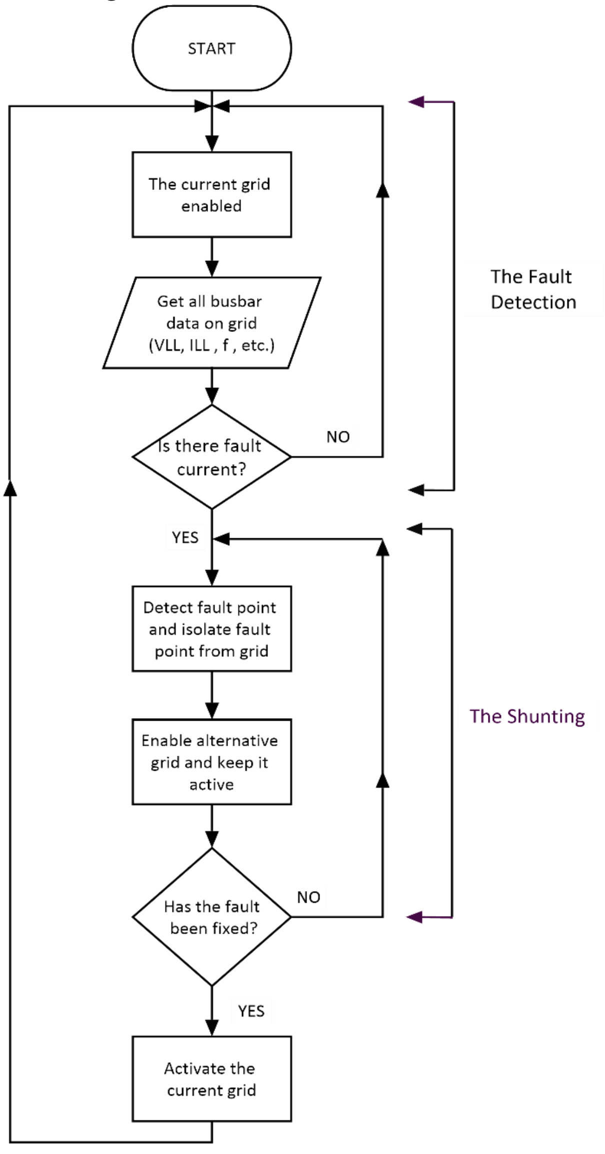

Figure 1. The Maneuver Algorithm

2.2. The Microgrid and Energy Management

The separating regions into microgrids is a solution proposal so that the consumers and grid components are not affected by faults. For this reason, the autonomous operation of microgrids in island mode becomes important in case of failure. The microgrid technology is recommended to ensure efficient integration of distributed renewable energy sources and it is very important to ensure the safety and stability of the microgrid under short circuit failures [20].

Therefore, in order to minimize the damage that may occur on the line, the micro grid was autonomously put into island mode. Meanwhile, the total power that the PV plant can feed is kept in the circuit and the load that is noninferiority and extra has been automatically disengaged by measuring the instantaneous power consumption values of the loads connected to the microgrid In the event of a fault, the working algorithm of the microgrid and energy managementhas been given in Figure 2.

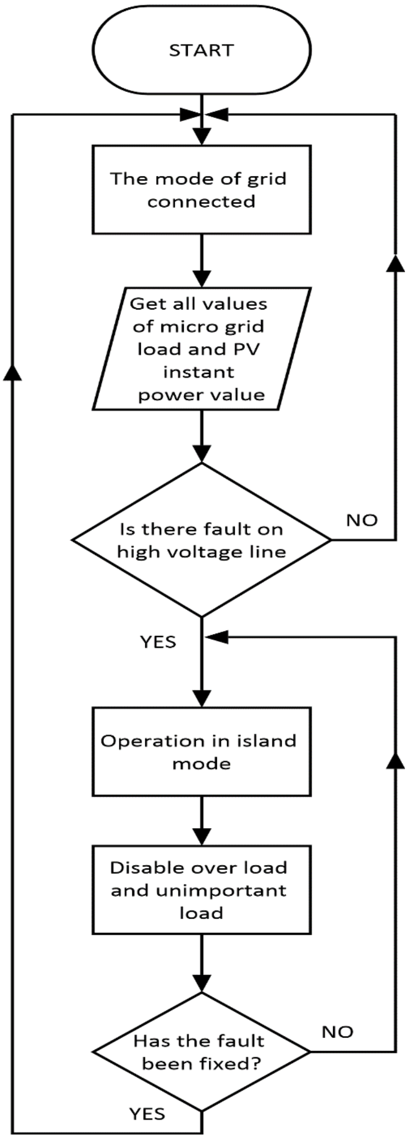

Figure 2. The Algorithm of Island Mode and Energy Management

2.3. The Design of SFCL

In case of failure in the grid, the precautions must be taken to avoid damaging the loads and other components in the microgrid, since the current characteristics of renewable power plants change during entry-exit to island mode. At this point, the first solution that comes to mind is to control the power with the semiconductor technology architecture. However, since the mentioned areas are very large loads and there is no semiconductor material to control such large loads, this option does not provide a definitive solution. The most effective solution here is to connect micrograms to the grid with the SFCL. Although SFCL technology is an expensive technology today, it is thought to be one of the indispensable components of smartgrid architectures in the future.

The SFCL is a grid element that performs power limitation quickly within a quarter cycle without power loss during normal sensing time and without additional sensing device. This circuit element limits the fault current without adding impedance to the circuit during normal operation, unlike reactors or high impedance transformers. The working principle of SFCL is based on the ability to phase change between the superconductivity state and the non-superconductor state of the superconducting material. Superconductors are materials that automatically change their resistor to a value higher than zero when a certain critical current value is exceeded. Since the working principle of SFCL was originally based on superconducting materials that can operate at very low temperatures, the widespread use of superconductor fault current limiters in electrical installations was much more expensive. The cooling problem has been greatly reduced with the discovery of high temperature superconductors (HTS). These new HTS materials can be operated at much higher temperatures and can be easily cooled using liquid nitrogen [20]. The superconductive damping behavior in the application model of SFCL is defined as adding a high resistance to the system at high currents. The resistance of the superconductor is a function of current density, temperature and magnetic field. A shunt resistor is required in parallel with the superconductor to deflect most of the overcurrent after quenching to prevent overheating. As long as the current density, temperature and magnetic field parameters are below critical levels in the model, the resistance will remain in a superconducting state. However, when these parameters begin to exceed the critical threshold, the superconductor starts the damping process and increases its resistance [21].The designed SFCL in the Simulink environment was modeled according to the resistance change approach due to overcurrent. This design model was made according to the formulation given in Equation-1 and Equation-2.

$$I_L = \frac{V_L}{R_{SFCL}+Z_L} \tag{1}$$

Here, the I_L is line current, the V_L is nominal voltage of the line, the Z_L is line impedance, and the R_{SFC} represents shunt-connected ohmic SFCL resistance

$$R_{SFCL} \leftrightarrow \begin{cases} R_{SFCL} \cong 0, & I_L < I_{CRT} \\ R_{SFCL} = R_{max}(1 - e^{-t/\tau}), & I_L \geq I_{CRT} \end{cases} \tag{2}$$

R_{max} is the maximum shunt resistance, which will eliminate the error and I_{CRT} is the critical current threshold value determined in the designed model. If the line current exceeds this current value, the R_{SFCL} resistance change is given in Equation 2.

3. THE SIMULATION MODEL AND RESULTS

The 5 busbar ring type grid has been constructed in the designed model. The energy source has been selected at 3Φ 120 kV level and unlimited power. Energy flow to the distribution line is provided by 120 kV / 25 kV lowering transformers. The distribution line is constructed according to the π circuit model. Also two loads of 15 MVA and 20 MVA power have been added to the grid. In addition, a micro grid with a 400 kW PV power supply and a load of 460 kW was connected to the ring grid. The designed SFCL was added to model to minimize the fluctuations that will occur during the connection of this microgrid to the grid. The designed simulink model is given in Figure 3.

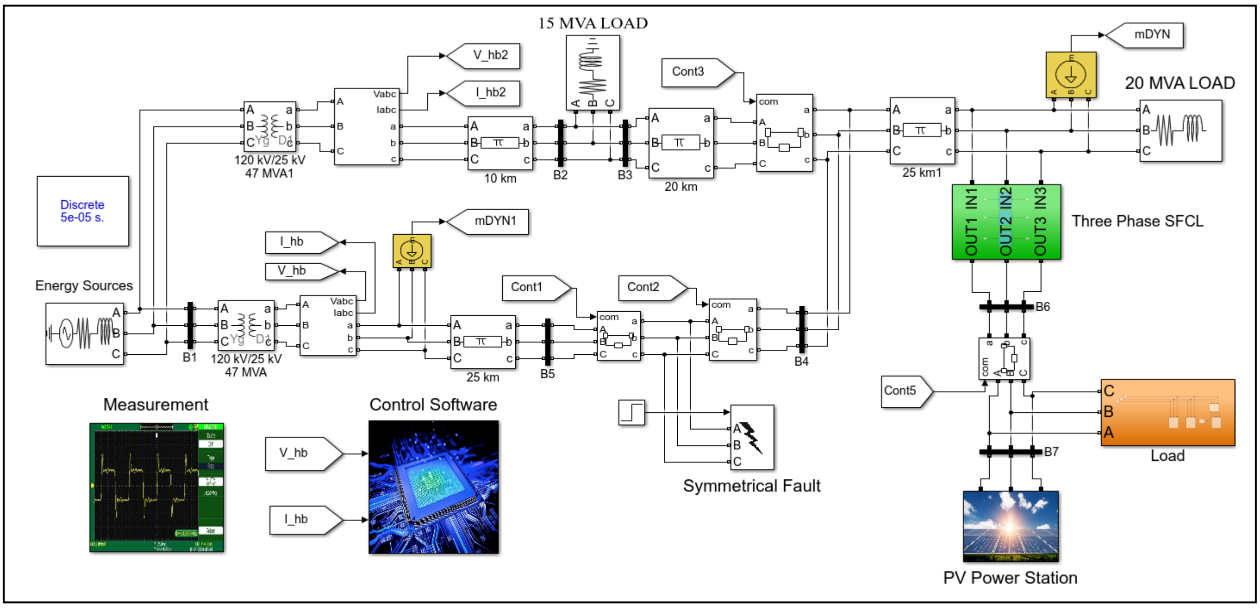

Figure 3. The Simulink Model

When the Simulink model has been run, the region where the fault is located has been isolated from the line in a very short time (half cycle) with the designed smart grid control algorithm after the symmetrical fault between the B4 and B5 busbars at t = 1 second. The 3-phase current changes have been given before and after the fault on the lines with busbar B1 and B2 in Figure 4 and Figure 5.

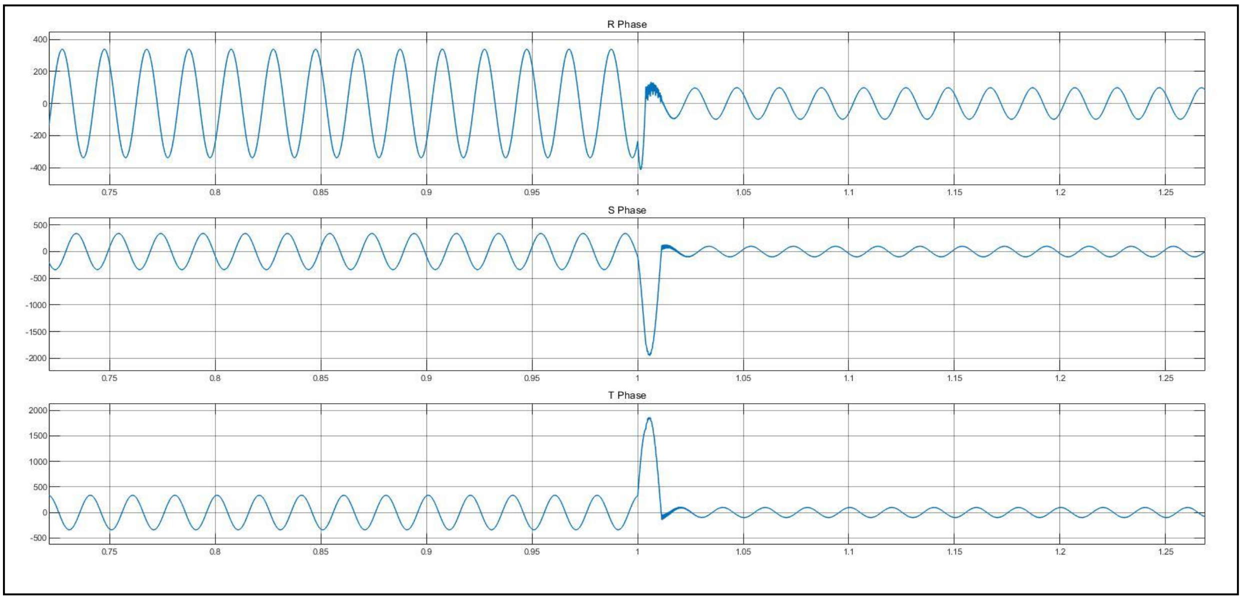

Figure 4. The B1 Busbar 3 Phase Current Graph

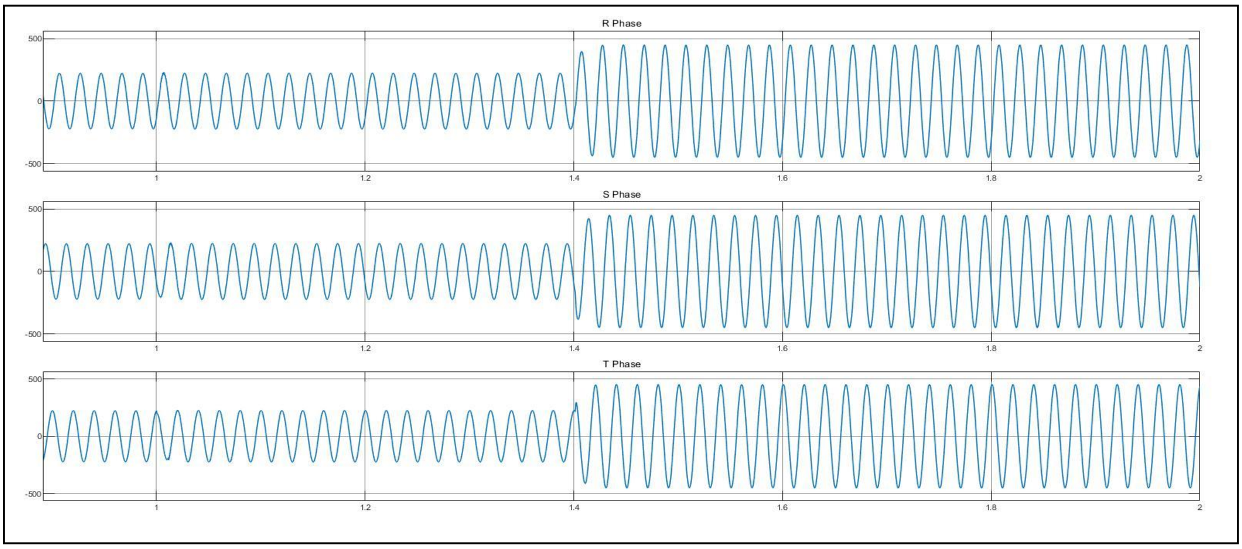

Figure 5. The B2 Busbar 3 Phase Current Graph

When the current graphs of busbars B1 and B2 have been analyzed, it is understood that the fault occurred after t = 1 second and the fault area has been isolated. Only The loads which before the fault zone has been continued to supply on the line with busbar B1.

After isolating the fault zone (t = 1.4 sec), the necessary maneuvering has been performed and the load with 20 MVA power has started to be fed from the line where B2 busbar has been located.

However, until the fault occurred and the fault zone has been isolated from the line (t = 1-1.4sec), the microgrid has been separated from the ring grid. In this time interval, energy management has been carried out in order to provide energy flow to the priority loads that the PV power supply could feed alone. For this reason, it has been ensured that the micro grid works steadily by throwing the load that is noninferiority and extra.

It has been observed that large power fluctuations occurred during the entrance and exit of the microgrid to the island mode and it has been given in Figure 6. The designed SFCL has been added to the simulink model so that the active and reactive power fluctuations do not damage the loads and the grid components. Simulation results using SFCL element are given in Figure 7.

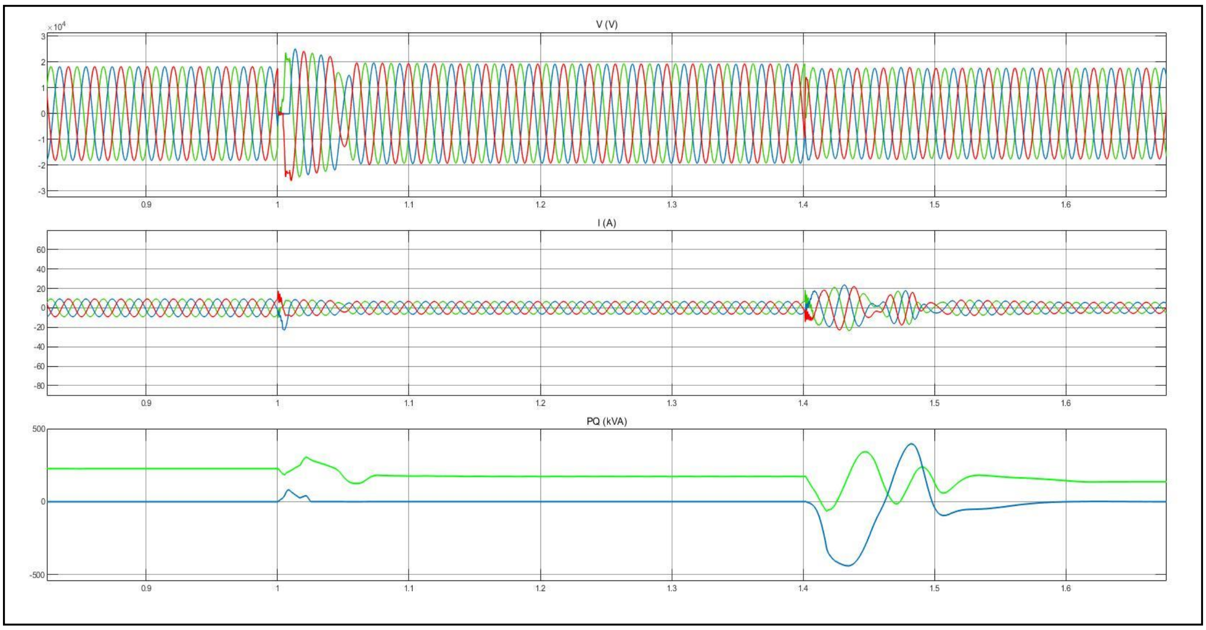

Figure 6. The Simulation Result without SFCL

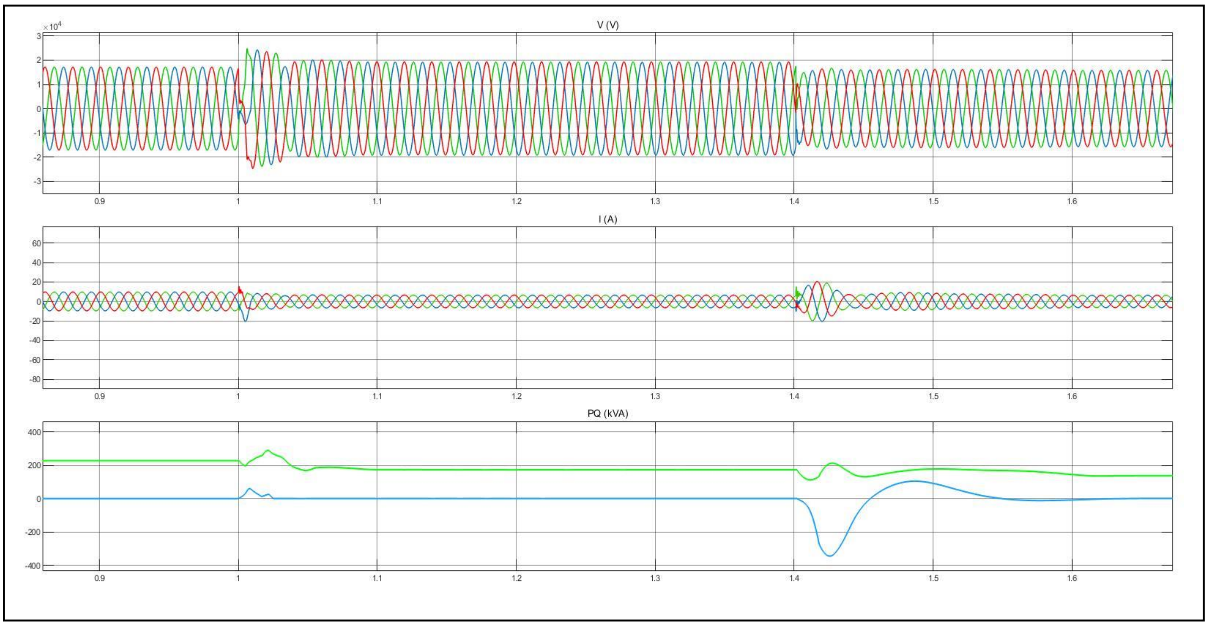

Figure 7. The Simulation Result with SFCL

When the graphs are analyzed, it is seen that the micro grid operates in island mode from the moment the fault occurs (t = 1 sec) until the moment the fault is eliminated (t = 1.4). It is seen that the designed SFCL element suppresses active and reactive power fluctuations both during the transition to island mode and connection to the network. Also, it has been observed that it reaches more stable and faster nominal operating values after network connection. According to simulation results, it is observed that active-reactive power fluctuations were suppressed and the frequency response of the system increases with SFCL.

At this point, even though there are SFCL elements, small power fluctuations can affect adjacent relay, breaker etc. line components. Therefore, the relay coordination should be done taking this situation into account in the designed network architecture. In this context, before applying, it is necessary to adapt the appropriate relay coordination to the designed network by making simulations of this type

4. CONCLUSION

The quality and continuity of energy are essential for customer satisfaction. It is predicted that the rapid increase in energy consumption and the fact that electric vehicles (EVs) will enter our lives in the future will cause the existing network architecture to be insufficient Therefore, transition to smart grids is inevitable. An ideal smart grid architecture is envisaged with this study and supported by simulation results.

As a result of the simulation study, the fault point has been determined. Subsequently, the most optimum maneuver management has been carried out and the existing loads have been fed. In addition, it is envisaged that the regions will be separated into micro grids for the continuity of energy flow and network frequency stability. In the designed network model, the region where the PV plant is located has been operated in island mode. Also, designed SFCL has been added to the system to limit the transient overcurrents occurring during the transition and exit, and the power fluctuations have been suppressed in the system.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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