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| IZMIR KATIP CELEBI UNIVERSITY    DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING  EEE 306  POWER SYSTEMS  Res.Asst. Mehmet Uğur SOYDEMİR  LOAD FLOW ANALYSIS OF A POWER SYSTEM  Derin Arda ŞAHİN 160403035  2020-2021 SPRING  ASST. PROF. DR. İBRAHİM ŞENGÖR   1. **ABSTRACT**    In this project, it is aimed to design a real power system and then make a load flow analysis of the system to show the working principle of the system. Within the scope of these purposes, an article about a real power system was found and simulated via simulation program Simulink. Output graphs and result tables were created with the reference of system outputs. The system that was modelled is designed by using IEEE 9-bus system and theoretical calculations were made with the help of Gauss-Seidel Method. The datas obtained from the Simulink were compared with the theoretical calculations and added to the report. For this report, in general, an ideal system was designed with the theoretical values of the IEEE 9-bus system and a detailed analysis of the system was made. The results that were obtained were interpreted.   1. **INTRODUCTION**   Power systems are networks consisting of multiple smaller systems. Generation, distribution and transmission are examples of these systems. While designing the power system, there are certain main components for the developed power system: transformer, switchboard, transmission line, substation, distribution line and distribution centers.[\*] In the designed system, there must be an energy source connected to the system and electrical devices are needed to collect and distribute the energy produced from the source that is called Bus. Buses are conductive structures that collect, distribute and control electrical energy of the same voltage and frequency. If the number of buses in the system increases, the system becomes more complex and energy can be distributed over a much larger area. The power system must be stabilized and analyzed for the correct distribution of electrical energy. For analysis, a bus called slack bus is assigned as a reference and calculations continue over this bus.[\*\*] Power flow analysis must be used to analyze the power system correctly. The reason for this is to observe whether the energy obtained is sufficient and whether the generator reaches its ideal operating capacity. The power flow analysis includes the voltage in the transmission line, the current passing through the crossover line, and the system losses. Since power flow equations are nonlinear, these cannot be solved analytically.[\*] A numeric iterative algorithm must be followed such as Gauss-Seidel or Newton-Raphson method.   1. **METHODOLOGY**   Power systems must operate in a stable state. In order for the system to work in a stable state, the system values should not exceed the determined values. However, the production and consumption facilities added to the system prevent the system from working stably. Power flow analysis is used to determine the changes that are caused by the parts which are added to the system. In this study, a power system was built using analytical and observational data. Then necessary analyzes were made. It was decided that the power system to be built would be a IEEE 9-bus power system. In order to analyze the system to be created, various topics were determined and necessary research was carried out. Explanations have been made on the following topics.   * **BUSES USED IN POWER SYSTEM**   Static analysis for voltage stability in power systems can be evaluated with curves (PV, QV and SV) showing the voltage-power relationship in busses. These voltage profiles determine the operating point of the system for different load levels and provide information about the evaluation of voltage stability limits and a potential voltage collapse. More importantly, with the help of these curves, many applications such as keeping the source voltage at different values, making series or shunt compensation at different percentages in the transmission line, planning the transmission lines and determining the transfer limits can be done.   * **LOAD FLOW ANALYSIS METHODS IN POWER SYSTEMS**   With the growth and development of power systems, the need for detailed analysis has emerged in the planning and operation stages. The analysis of these systems, which are quite complex, is also difficult, but with the technological developments, computer systems have started to be used in the analysis of power systems. Thus, it has become easier to use numerical methods that converge to difficult-to-compute results by using large numbers of iterations. Two of these methods that used for this study are briefly described below;   * **Gauss-Seidel Method**   The Gauss-Seidel method was developed based on the Gauss method used for solving nonlinear algebraic equations. The Gauss-Seidel method has the principle that the calculation is terminated when the difference between the new busbar voltages calculated in a power system with n busbars and the busbar voltages found in the previous iteration is less than the error value specified by the user.   * **Newton-Raphson Method**   The Newton-Raphson method is based on the Taylor series expansion of functions with two or more variables and the neglect of partial derivatives greater than 1’st order in the Taylor series expansion. Many electric companies use Newton's method procedures to analyze power systems.  Many articles were reviewed and it was seen that in the Newton-Raphson method, active and reactive power losses are calculated almost close to each other but in the Gauss-Seidel method the active and reactive power losses increase as the tolerance value decreases.In both load flow analysis methods, the powers produced by the generators are calculated as close to each other according to the load demands on the busbars. It has been observed that the Newton-Raphson method has the best results for busbar systems due to the large number of iterations and the increase in losses as the tolerance value decreases in the Gauss-Seidel Method.   * **PARAMETERS THAT MAY AFFECT THE RESULTS**    Power flow analysis is a critical calculation in both the design and operation of a power system. All parameters that may have an impact on the computation outcomes must be considered. A power-flow study focuses on many aspects of AC power characteristics, such as voltages, voltage angles, real power, and reactive power and typically uses simplified notations such as a one-line diagram and per-unit system. It examines power systems in their usual steady-state state of operation. Power-flow or load-flow studies are critical for both planning future power system expansion and deciding how to best operate current systems. The magnitude and phase angle of the voltage at each bus, as well as the actual and reactive power flowing in each line, are the main findings of the power-flow analysis. Voltage stability is affected by active-reactive power fluctuation and transmission line lengths. Furthermore, transformer stages and series capacitor connections have an impact.(\*\*\*) As a consequence of the situation analysis, it has been discovered that increasing active and reactive power at the consumer level lowers voltage levels in the power system. On the other hand, because transmission line lengths generate an inductive rise, it has been discovered that increasing transmission line lengths causes both an increase in losses and a fall in voltage. Changes in these values lead the analysis to differ.(\*\*\*\*)  After researching the determined topics, various articles were searched for the power system to be created.The numerical values of the 9 bus power system to be created from the researched articles were obtained and the results were interpreted by simulating the system in the Matlab Simulink environment.   1. **SIMULATION RESULTS**   The load flow analysis and transient stability for the standard IEEE 9-BUS system are performed by using Simulink. As shown in the single line diagram Figure 1. ???  f    Figure 1: Single-line diagram of an IEEE 9-bus system [1].  The values given in the tables are used to simulate the power system. In Table 1, the values of synchronous machine parameters are given for G1, G2 and G3 generators.   |  |  |  |  | | --- | --- | --- | --- | | SYNCHRONOUS MACHINE PARAMETERS | G1 | G2 | G3 | | Nominal Power (MVA | 247500000.00 | 192000000.00 | 128000000.00 | | Nominal Voltage (kV RMS L-L) | 16500.00 | 18000.00 | 13800.00 | | Xd (pu) | 0.36 | 1.72 | 1.68 | | X'd (pu) | 0.15 | 0.23 | 0.23 | | X''d (pu) | 0.10 | 0.1728 | 0.19 | | T'do (s) | 8.96 | 6.00 | 5.89 | | T''do (s) | 0.00 | 0.001 | 0.00 | | Xq (pu) | 0.24 | 1.65 | 1.61 | | X'q (pu) | - | 0.23 | 0.23 | | X''q (pu) | 0.10 | 0.1728 | 0.19 | | T'qo (s) | - | 0.53 | 0.60 | | T''qo (s) | 0.00 | 0.001 | 0.00 | | Ra (pu) |  |  |  | | Xl (pu) | 0.06 | 0.4224 | 0.31 | | H (s) | 9.55 | 3.33 | 2.35 | | F(pu) | 0.00 | 0.00 | 0.00 | | f(Hz) | 60.00 | 60.00 | 60.00 | | Active power generation P (W) | 150000000.00 | 1.63E+08 | 85000000.00 |   Table 1: The datas of the parameters of the generators.           |  |  |  |  | | --- | --- | --- | --- | | TRANSFORMER | G1 | G2 | G3 | | S | 247500000.00 | 192000000.00 | 128000000.00 | | V1 | 16500.00 | 18000 | 13800 | | V2 | 230000 | 230000 | 230000 | | R1 | 1.00E-06 | 1.00E-06 | 1.00E-06 | | R2 | 1.00E-06 | 1.00E-06 | 1.00E-06 | | L1 | 0 | 0 | 0 | | L2 | 0.0576 | 6.25E-02 | 0.0586 | | Rm | 500 | 5.00E+02 | 500 | | Lm | 500 | 5.00E+02 | 500 |   Table 2: Transformer Datas   |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | TRANSMISSION LINE | Length (km) | R0 (Ω/km) | R1 (Ω/km) | L0 (H/km) | L1 (H/km) | C0 (F/km) | C1 (F/km) | | 4 TO 5 | 89.93 | 5.88E-01 | 5.88E-02 | 3.98E-03 | 1.4E-03 | 5.89E-09 | 9.81E-09 | | 4 TO 6 | 97336,00 | 9.24E-01 | 9.24E-02 | 3.98E-03 | 1.4E-03 | 4.88E-09 | 8.14E-09 | | 5 TO 7 | 170.338 | 9.94E-01 | 9.94E-02 | 3.98E-03 | 1.4E-03 | 5.41E-09 | 9.01E-09 | | 6 TO 9 | 179.86 | 1.15E+00 | 1.15E-01 | 3.98E-03 | 1.4E-03 | 5.99E-09 | 9.98E-09 | | 7 TO 8 | 76.176 | 5.90E-01 | 5.90E-02 | 3.98E-03 | 1.4E-03 | 5.89E-09 | 9.81E-09 | | 8 TO 9 | 106.646 | 5.90E-01 | 5.90E-02 | 3.98E-03 | 1.4E-03 | 5.90E-09 | 9.83E-09 |   Table 3: Transmission Lines Datas   |  |  |  |  | | --- | --- | --- | --- | | LOAD PARAMETER | Load5 | Load6 | Load8 | | Nominal Active Power (MW) | 125.00 | 90.00 | 100.00 | | Nominal Reactive Power (MVar) | 50.00 | 30.00 | 35.00 |   Table 4: Load Datas   |  |  |  |  | | --- | --- | --- | --- | | EXCITER PARAMETERS | G1 | G2 | G3 | | Ka | 20.00 | 20.00 | 20.00 | | Ke | 1.00 | 1.00 | 1.00 | | Kf | 0.06 | 0.06 | 0.06 | | Tr(s) | 0.02 | 0.02 | 0.02 | | Ta(s) | 0.20 | 0.20 | 0.20 | | Te(s) | 0.31 | 0.31 | 0.31 | | Tf (s) | 0.35 | 0.35 | 0.35 | | VRmin(pu) | -3.00 | -4.00 | -4.00 | | VRmax(pu) | 3.00 | 4.00 | 4.00 | | SE1 | 0.48 | 0.48 | 0.48 | | SE2 | 0.14 | 0.14 | 0.14 | | E1 | 3.10 | 3.10 | 3.10 | | E2 | 2.30 | 2.30 | 2.30 |   Table 5: Exciter Parameter Datas of Generator   1. **FINDINGS**   The load flow analysis and fault analysis applied to the standard IEEE 9-BUS system are performed by using Matlab / Simulink. The IEEE 9-Bus system consists of 9 buses, 3 generators, 3 loads and 3 transformers. The load flow power base value selected as 100 MVA and frequency selected as 60 Hz.   * **LOAD FLOW ANALYSIS**   The load flow for our system is converged in 2 iterations at the simulation. Simulation converged by Gauss-Seidel.   * Table 6 shows the total generated, loaded and lossed power values. Total power losses approximately the %1 of the total generated power.  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  | Total Power Datas | | |  | | Total Generation | | 319.9569 | 10.35668 | | | Total PQ Load | | 315 | 115 | | | Total Z Shunt | | 1.267899 | 1.209657 | | | Total Losses | | 3.689046 | -105.853 | |   Table 6: Total Power Datas   * Table 7 shows the load flow bus analysis and Table 8 shows the list of power flow between the busses.  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | Bus No | Type | Nominal  Voltage(kV) | Voltage  (pu) | Angle  (deg) | Gen  (MW) | Gen  (MVAR) | Load  (MW) | Load  (MVAR) | | 1 | Swing | 16.5 | 1.04 | 0.00 | 71.95694 | 14.21672 | - | - | | 2 | PV | 13.8 | 1.025 | 6.74 | 163 | -0.56423 | - | - | | 3 | PV | 18 | 1.025 | 3.16 | 85 | -3.29581 | - | - | | 4 | PQ | 230 | 1.037 | 29.12 | - | - | -1.3E-7 | -2E-7 | | 5 | PQ | 230 | 1.004 | 26.79 | - | - | 125 | 50 | | 6 | PQ | 230 | 1.017 | 27.30 | - | - | 90 | 30 | | 7 | PQ | 230 | 1.027 | 33.86 | - | - | 2.8E-7 | 6.55E-8 | | 8 | PQ | 230 | 1.014 | 30.30 | - | - | 100 | 35 | | 9 | PQ | 230 | 1.027 | 31.05 | - | - | 5.53E-8 | -3.2E-7 |   Table 7:Load Flow Bus Datas   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Bus  (From) | Bus  (To) | Device Type  (Branch) | P(MW) | Q(MVAR) | Loss(MW) | Loss(MVAR) | | 1 | 4 | Transformer | 71.42154 | 13.68134 | 0 | 1.13784 | | 2 | 7 | Transformer | 162.5966 | -0.96767 | 0 | -8.1976 | | 3 | 9 | Transformer | 84.73104 | -3.56476 | 0 | -3.13396 | | 4 | 5 | Line | 51.00049 | 24.26551 | 0.34569 | 15.23909 | | 4 | 6 | Line | 20.42102 | -11.722 | 0.16912 | 13.7355 | | 5 | 7 | Line | 0.001623 | -0.00179 | 2.948E-3 | 1.809E-3 | | 6 | 9 | Line | -69.7481 | -4.54246 | 0.79779 | -11.96038 | | 7 | 8 | Line | 86.46238 | 2.749032 | 0.60938 | 10.061468 | | 8 | 9 | Line | -14.147 | -22.1895 | 0.03804 | 21.470304 |   Table 8: Power Flow Datas   * **FAULT ANALYSIS**   A three phase short circuit balanced fault applied on the transmission line between bus 5 and bus 7 at 1.0s (tf=1.0s) and was cleared at 1.083s (tc=1.083s). Which means 0.083s is the fault clearing time.   * The rotor angle of all three generators is shown in Figure 1.     Figure 2: Rotor angles of 3 generators   * Relative angle plot of all generators w.r.t generator at bus 1 shown in Figure 2.     Figure 3:Relative angle plot w.r.t generator at bus 1   * Absolute angle plot of all generators of IEEE 9 bus system shown in Figure 3.     Figure 4:Absolute Angle Plot of Generators.   1. **CONCLUDED REMARKS**   In this study, load flow analysis of IEEE 9-Bus System has been investigated. Effects of faults and power flow analysis parameters found by using Matlab/Simulink. All simulation results have been presented. For the transient analysis, firstly, the effects of active-reactive power increases and transmission line length are evaluated. After that the effects of series capacitors and transformers were investigated. The fault is implemented between bus 5 and bus 7 also circuit breakers have been used between the buses. The effect of fault has been investigated and the effect of place of the fault has been investigated.  As a conclusion of load flow analysis, power effect on busses and the voltages was observed. While active and reactive power increases voltage levels have decreased. On the other hand, while the length of the transmission line is increased, transmission losses have increased and the voltage levels have decreased. As a conclusion of fault analysis, the system has reached its stability. The effect of fault at different places showed different effects and stabilities.  The renewable system has been implemented by adding three wind turbines instead of three synchronous generators to our 9 bus system.The results that were observed, supported the results of the load flow analysis.   1. **APPENDIX A**  * **RENEWABLE ENERGY INTEGRATION INTO THE POWER SYSTEM**   As societies continue to develop and the world population increases, the need for electricity increases exponentially. In order to meet this need, traditional energy production methods continue to be used in the world. However, the decrease in fossil fuels, the increase in the greenhouse gas effect and the increasing energy need have led people to seek new energy production ways. The best option for this situation is the use of renewable energy sources in energy production. Renewable energy can be defined as the energy source that can be available the next day in nature's own evolution. In today's electricity grids, the integration of renewable energy sources into power systems is becoming increasingly common. Many sources, especially wind and hydroelectric power, are used in electricity production, and some countries meet a large part of their energy needs from these sources. However, this situation has disadvantages. In some cases, continuous production cannot be achieved from renewable energy sources. This situation may disrupt the stability of the system. Therefore, it is important to analyze the effects of renewable resources on power systems. In the future, energy sources such as solar and wind will be used more in power system design, in which case it will be even more important to ensure the stability of the load flow in the power system. Analyzing the negative situations that may occur in the system beforehand and taking precautions when necessary is an important step for the correct operation and effective management of the power system.  (https://dergipark.org.tr/en/pub/emobd/issue/5505/74666)    I integrated the wind turbine into the 9 busbar power system I created. As a result of the analysis, it has been seen that renewable sources do not cause a serious change in the voltage level and there may be decreases in the power factor.   1. **REFERENCES**   **\***[**Güç Sistemi Nedir? Güç Sisteminin Tanımı ve Yapısı - Circuit Globe**](https://circuitglobe.com/power-system.html#:~:text=The%20power%20plant%2C%20transformer%2C%20transmission,through%20the%20transformer%20for%20transmission.)  **\*\***Glover, J.Duncan.,Sarma,Mulukutla S.,Overbye,Thomas J.,Power System Analysis and Design.1994.6(4):p.326.  (\*\*\*)[Microsoft Word - 5- IJESG VOL 1 (1) Berat EFE.docx (dergipark.org.tr)](https://dergipark.org.tr/tr/download/article-file/398329)  (\*\*\*\*)[Difficulties faced in choosing the Voellmy coefficients in Design of Avalanche Barriers at Trabzon, Uzungöl (dergipark.org.tr)](https://dergipark.org.tr/en/download/article-file/229783) |