Electrical Power System Final Project

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***Abstract*— In Module 3, Final Project for the Electric Power System Practical, power system on a city scale was made based on given real-world load specifications. These include residential, industrial, priority, public, and social loads. The design simulation is carried out using SimPowerSystems™ and Simulink® in MATLAB. Analyze the load for each type, considering their nature and daily operating times. Then, designed a suitable power supply system capable of reliably supporting each load category. This is achieved by designing a power generation capacity that is approximately 40% above the total power flow required by all loads. This module emphasizes the importance of technical calculations, including power generation capacity, transmission systems, and evaluating operational conditions, such as peak load operation. Furthermore, the power system design in this module is also implemented under several realistic scenarios, such as emergency cases where only priority loads are supplied, symmetrical fault conditions, and power supply configurations using different generators, such as Solar Power Plants (PLTS) and gensets. The goal of this module is to help students understand the real-world challenges in power system planning and to integrate technical and operational aspects into a single comprehensive system design.**

Keywords—Power Flow, Load, Power Plant, Power Supply System, Electric Power System, Simulink.

I. Introduction

This major assignment designs a power system based on given load specifications, transmission networks, and constraints, simulated in Simulink. It includes load scheduling, generation scheduling, line and transformer sizing for a city's power system. Designs cover emergency scenarios with only priority loads supplied, handling line outages, simulating three-phase faults, and special generation capacity designs. Specific scenarios include: 1. Solar Power Plant (PLTS) supplying RT-1, RT-2, RT-3, worship area, and streetlights. 2. Gensets supplying RT-4, RT-5, schools, universities, and all industrial loads during emergencies. 3. A combined scenario of conditions 1 and 2.

The module aims to design generation and load schedules, create a power system based on specifications, analyze short-circuit faults, and design generation capacity for specific conditions.

II. Theory

2.1 Power Flow Analysis

Power flow analysis calculates voltages, currents, active and reactive power, and power factors (pf) in a power system. The design and operation of power systems require these calculations to analyze system performance under steady-state conditions in various operating scenarios. In this major assignment, power flow analysis is performed using Simulink in MATLAB. Problems are solved by determining the power flow in each line and transformer in the network, as well as the magnitude of the voltage and phase angle at each busbar in the network, after the power consumption data at the load points and power production at the generator side are known.

Power flow analysis makes it easier to understand the performance of a power system that has specific criteria such as component and circuit loading, bus voltages under steady-state conditions, reactive power flow, and system losses

2.2 Generator, Transmission Network, and Load

Generator is the primary device used in an electric power system. It converts mechanical energy into electrical energy through the principle of electromagnetic induction. Synchronous generators are commonly used in power systems because they can produce voltage with stable frequency and magnitude. Generators have three modes of operation, voltage controller, reactive power controller, and power factor controller. Generators generally have governors and AVRs. A governor is a device that functions to maintain the rotational speed of the generator. For example, when the load increases, the rotational speed will decrease, so the governor opens the fuel valve wider, causing the rotational speed to remain constant. An AVR (Automatic Voltage Regulator) is a device that regulates the output voltage of the generator by controlling the motor's excitation current.

Transmission network serves to transmit electrical energy from the generating center to the load center on a large scale and over long distances. This network operates at high voltage to reduce power losses due to current. This transmission network differs from the distribution network. Where transmission networks usually use voltages above 70kV, while distribution networks usually only use voltages up to 33kV.

Load is a component that consumes electrical energy. Loads can be resistive, inductive, or capacitive, depending on their characteristics. Loads come in two types: static and dynamic. Static loads are loads that do not change with time, such as lamps and TVs. Dynamic loads are loads that change with time depending on their operation. Examples include electric motors (depending on needs) and AC (depending on outside temperature and user demand).

2.3 Short-Circuit Analysis

Short-circuit analysis is used to determine the magnitude of current flowing through the lines of a power system at specific time intervals when a short-circuit fault occurs. The magnitude of the current flowing through the lines during a short-circuit fault will change over time until the current reaches its steady-state value. Within that time interval, the protection system must be designed to detect, interrupt, and isolate the fault.

Several types of faults can occur in a system. The first is a symmetrical fault, which involves all three phases simultaneously. The second is an unsymmetrical fault, which occurs when one or two phases have a fault. There are three types of unsymmetrical faults, phase-to-phase fault, single line-to-ground fault, and double line-to-ground fault. Symmetrical faults are characterized by equal fault currents in all three phases. This leads to very high currents that often damage other components in the power system. However, symmetrical faults are the least common. Unsymmetrical faults are characterized by unbalanced currents and voltages during the fault and are more frequent.

To prevent equipment and system damage caused by short-circuit faults, protection systems are implemented. These systems minimize the impact of the damage and facilitate fault isolation. Protection systems must have a fast response time and function reliably when needed. Common components of a protection system include relay to detects faults in current or voltage and sends a signal to the circuit breaker upon detection, circuit breaker to interrupts the flow of electrical current upon receiving a signal from the relay, recloser for automatically interrupts and restores the electrical current flow, fuse that melts when the current exceeds a certain limit., load break switch to interrupts and connects electrical current specifically under loaded conditions and disconnecting Switch to isolates a power system when it is in a no-load condition.

III. SYSTEM DESIGN

The power system designed in this project used specification detailed in the given document. This city has 4 main sectors: household, industrial, priority, and public. The industrial and priority sectors will always be on 24/7, meanwhile the household and public sectors are scheduled as below.

Sectors	Load Types	Schedule		
		05.00-17.00	17.00-22.00	22.00-05.00
Household	Television	☐	☑	☐
	Lamps	☐	☑	☑
	Refrigerators	☑	☑	☑
	AC	☐	☐	☑
	Dispenser	☑	☑	☑
	Water Heaters	☐	☐	☑
	PC	☑	☑	☐
Public	Religion Buildings	☑	☑	☑
	Schools and Universities	☑	☑	☐
	Streetlights	☐	☑	☑

Fig. 1. City load scheduling.

Using this schedule and the specification given, the total demand based on apparent power for this city can be seen below.

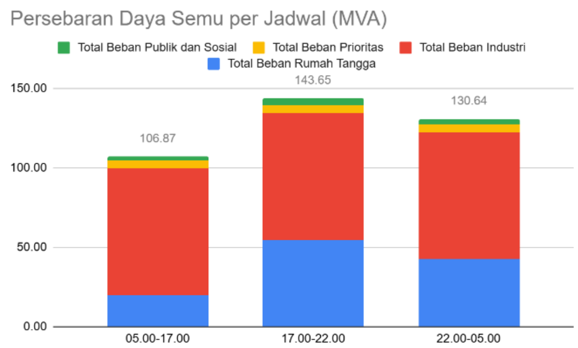

Fig. 2. Total demand based on apperent power for each schedule.

As can be seen above, the maximum demand happens at 17.00-22.00 with the total of 143.65MVA. Meanwhile, the minimum demand happens at 05.00-17.00 with the total of 106.87MVA.

This information can be used to determine the minimum capacity for each power plant. There are a total of 4 power plant in this city: PLTP (geothermal), PLTU (steam), PLTA (hydro), and PLTB (wind). PLTP and PLTU will be active for the whole day, while PLTA and PLTB will be active only at night.

In this system, the ratio of power capacity is given by PLTP : PLTU : PLTB : PLTA = 0.8 : 1.0 : 0.3 : 0.1. The total power produced must exceed a minimum of +40% from the total demand calculated before. Based on these specifications, the determined power capacity can be seen below.

Jadwal	Kapasitas Maksimum Pembangkit (MW)			
	PLTP (swing)	PLTU (pv)	PLTA (swing)	PLTB (pv)
05.00-17.00	80.00	100.00	0.00	0.00
17.00-22.00	80.00	100.00	30.00	10.00
22.00-05.00	80.00	100.00	30.00	10.00

Jadwal	Kapasitas Maksimum Pembangkit (MVA)			
	PLTP (swing)	PLTU (pv)	PLTA (swing)	PLTB (pv)
05.00-17.00	94.12	117.65	0.00	0.00
17.00-22.00	94.12	117.65	35.29	11.76
22.00-05.00	94.12	117.65	35.29	11.76

Fig. 3. Each plant apparent and active power capacity.

Jadwal	Total Kapasitas Maksimum (MW)	Total Seluruh Beban (MW)	Perbedaan Maksimum (%)
05.00-17.00	180.00	97.1900	46.01%
17.00-22.00	220.00	131.9313	40.03%
22.00-05.00	220.00	119.6713	45.60%

Jadwal	Total Kapasitas Maksimum (MVA)	Total Seluruh Beban (MVA)	Perbedaan Maksimum (%)
05.00-17.00	211.76	106.8661	49.54%
17.00-22.00	258.82	143.6463	44.50%
22.00-05.00	258.82	130.6358	49.53%

Fig. 4. The produced power and total load difference.

The figure above confirms the minimum safety margin of +40% has been reached. The next step of design is to determine the Line and Trafo parameters needed for the circuit. These parameters are taken directly from the Medium/High Voltage Cable Catalogue by PT SUCACO Supreme Cable and the SPLN standard [1], [2], [3], [4], which can be seen below.

Line	Tegangan (Vline)	Panjang (km)	R (ohm/km)	L (mH/km)
Gardu 1-2, 1-4, 2-4	70kV	20	0.0601	0.6550
Gardu 1/2/4 - 3	70kV	5	0.0601	0.6550
Gardu 1 - PLTP	150kV	100	0.0601	0.6550
Gardu 2 - PLTU	150kV	100	0.0601	0.6550
Gardu 3 - PLTA	150kV	50	0.0601	0.6550
Gardu 4 - PLTB	150kV	20	0.0601	0.6550
Gardu 1 - Beban 1	20kV	3	0.2530	0.5530
Gardu 4 - Beban 4	20kV	3	0.2530	0.5530
Gardu 2 - Beban 2	20kV	0	0.2530	0.5530
Gardu 3 - Beban 3	20kV	0	0.2530	0.5530

Trafo	Konfigurasi	Daya Pengenal (MVA)	Impedansi (pu)
20kV/70kV	Wye-Delta	30	0.125
70kV/150kV	Wye-Delta	100	0.125
150kV/70kV	Delta-Wye	100	0.125
70kV/20kV	Delta-Wye	30	0.125
20kV/380V	Delta-Wye	2.5	0.07

Fig. 5. Line and Trafo parameter used in the design.

Based on all parameters determined before, below is the final design of the initial power system circuit for city A.

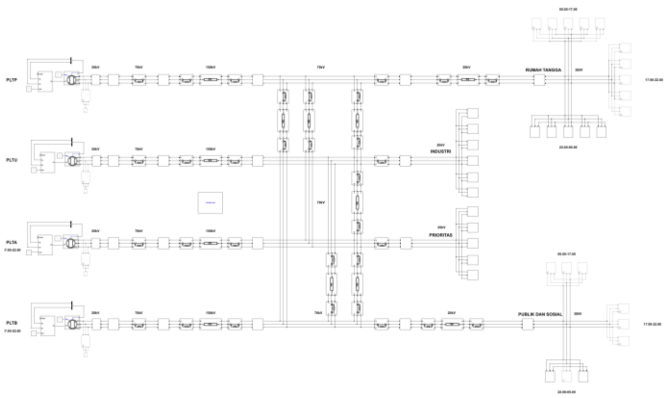

Fig. 6. The final design of the initial power system circuit for city A.

IV. Results and Discussion

4.1 Initial Condition Simulation

The first simulation showed that the initial circuit has yet to meet the specification. The simulated voltage for the household sector went as low as 0.8704pu (at 17.00-22.00), way below the desired minimum of 0.96pu. Meanwhile, the industrial district voltage was still below the specification minimum of 0.98pu, that is 0.9594pu at 05.00-17.00. Additional problems also arise from the fact that the PLTA plant contributed to more power than the PLTP, even though it has way less capacity.

To fix these issues, there are several changes that have been made to this system. First, to give a significant increase in the household voltage, additional parallel Line at the distribution system and tapping change of about -5% at the distribution trafo are needed. Second, tapping of industrial distribution trafo is also changed by about -2.5% to solve the undervoltage problem in the industrial district. Third, the transmission Line of PLTP is also added to increase the possible power potential of that plant.

After these changes, the simulation had proven that all the specifications were finally met. The voltage in the household sector jumped all the way up to 0.9689pu, which is above the minimum criteria. Meanwhile, the voltage in the industrial district increased to 0.9935pu, which is way above the specification. Other than that, the power usage of PLTP has also increased, which is good considering it has a quite high capacity (if compared to PLTA).

At the end, these first simulations have shown that the final design has met all the specifications, with the help of additional transmission/distribution line and tap changes of the distribution trafo.

4.2 Emergency Condition Simulation (Priority Loads Only)

The results obtained from the emergency condition simulation, where only priority loads were connected, show that the use of a single hydroelectric power plant (PLTA) was sufficient to supply the total demand. The PLTA delivered 12.7859 MW of active power and 1.3211 MVAR of reactive power to critical facilities such as the presidential palace, government offices, military base, data centre, and hospital. All load buses maintained a stable voltage level of 0.9981 per unit, which falls well within the acceptable operational range and above the minimum voltage specification of 0.96 pu. The highest recorded load was 2.0172 MW at the military base, while the data centre had the lowest at 0.0224 MW.

No signs of overvoltage, undervoltage, or power imbalance were observed throughout the network. These results confirm that PLTA alone can ensure reliable and efficient supply during emergency conditions, eliminating the need to operate additional generators such as geothermal (PLTP), coal-fired (PLTU), or wind (PLTB) units. This configuration supports a minimal yet robust design that maintains voltage stability and system efficiency when supplying only priority loads.

4.3 Fault Condition Simulation

The power system was tested under a fault scenario involving the disconnection of transmission lines at the substation supplying critical loads. The simulation was conducted with the assumption that it was daytime, and only PLTU and PLTP were operational. This assumption was made to simplify the analysis and improve the clarity of the results.

Initially, the simulation was run under normal conditions without any line disconnections. The current and voltage waveforms at the data center and hospital loads served as the baseline for comparison.

Subsequently, a fault scenario was simulated by disconnecting two lines at Substation 1-3. The results show that it takes approximately 1 second for the system to reach a steady state following the disturbance.

Another simulation was performed by disconnecting two lines at Substation 2-3. In this case, the system stabilized more quickly, reaching a steady state in approximately 0.6 seconds. This indicates that Generator 1 (a geothermal power plant, PLTP) is able to restore power to the critical loads more rapidly in this configuration.

A further scenario involved simultaneous disconnection of two lines at both Substation 1-3 and Substation 2-3. Even under this condition, power was still supplied to the critical loads through Substation 3-4. This substation receives voltage from Substation 1-4, but due to the longer transmission path, the system took longer to respond—achieving steady state in approximately 0.8 seconds—despite still relying on the same generator (PLTP).

Finally, a more severe scenario was simulated by disconnecting two lines at Substations 1-3, 2-3, and 3-4. Under this condition, no power was delivered to the critical loads. Although phase A remained physically connected, current did not flow due to the Delta-Wye configuration of the transformers and the Wye configuration of the loads, which require multiple phases for current circulation. As a result, all phase currents dropped to zero.

In another simulation, three-phase fault condition was conducted. In this test, the three-phase fault was placed on the Gardu 1–2 line. The fault occurred at t = 0.1 s – 0.6 s, and the circuit breaker switching occurred at t = 0.4 s – 1.3 s. This test scenario represents daytime conditions where only the PLTP and PLTU generators are active.

There can be observed a fault current spike at t = 0.1 s, indicating that a fault was occurred. Between t = 0.1 s – 0.4 s, the fault is active while the circuit breaker remains closed, resulting in low current to the loads. Between t = 0.4 s – 0.6 s, the fault remains active but the circuit breaker opens. As a result, the loads not affected by the fault recover normal voltage, while those isolated by the breaker continue to receive low or no current. However, in this configuration, where the loads are supplied by two generators, the unaffected generator resumes power delivery to the disconnected loads, restoring their current to normal as soon as the fault is isolated by the breaker.

To further clarify the analysis, a symmetrical fault condition was applied to the load line that connects to public facilities. The simulation shows that during the time interval t = 0.1 s – 0.4 s, when the fault is active and the circuit breaker is still closed, the load current drops significantly due to high fault current. Between t = 0.4 s – 0.6 s, although the fault remains active, the breaker opens, isolating the fault. The load connected downstream from the breaker is shut down, and this blackout persists until the breaker recloses at t = 1.3 s. Once the breaker recloses, both current and voltage return to normal levels. During symmetrical faults, the fault current spikes drastically. Hence, symmetrical faults are the most severe type of fault in a power system. However, they are also the least likely to occur compared to other unsymmetrical faults.

4.4 Solar Power Plant as Subsidiary Power Supply

The results obtained from the use of Solar Power Plants (PLTS) as an additional energy source, there has been an increase in the average voltage that is not too significant, with some slight overvoltage occurring in the power system. The reactive power values have also approached zero or even become negative, which is a concern as it has the potential to cause reverse reactive flows, like the conditions seen at coal-fired power plants (PLTU) during nighttime when the load from street lighting and places of worship decreases significantly.

This reduction in load results in an excess supply of power ranging from 5 to 8 MW, leading to an "underloaded" condition. While this has positive effects such as reducing the load on geothermal (PLTP), hydroelectric (PLTA), and biomass (PLTB) plants, thereby decreasing emissions from the generating units, it also has negative implications. The high reactive power leads to voltage levels on several lines approaching the 1.05 per unit limit. Additionally, the power plants become less efficient due to operating at lower loads. Modifications can be made by implementing voltage control on the PLTS to ensure that the power supplied is not excessive. It may also be beneficial to add tap transformers to reduce the voltage from the source when several loads are utilizing the PLTS as their power supply.

4.5 Generator Set as Subsidiary Power Supply

The generator set is added to each load with two possible connections, an on-grid connection where the load is still connected to the main power grid and an off-grid connection where the load is fully supplied only by the generator set.

Both simulations yielded roughly the same results, namely an increase in load voltage values and power absorption by the swing generator. The maximum voltage obtained for both conditions was 1.0227pu for on-grid and 1.0195pu for off-grid. These values indicate that the system did not reach overvoltage.

Meanwhile, the maximum absorption in both conditions was carried out by the geothermal power plant (PLTP) from 05:00 to 17:00 WIB, namely -46.1211 MW for on-grid and -48.9744 MW for off-grid. This absorption occurs because most of the load has been self-supplied by individual generator set, resulting in excess power that needs to be absorbed by the generator swing.

However, this absorption is not always desirable, as not all generators are designed to perform such absorption. Therefore, it is necessary to reduce the power capacity of each power plant to prevent excess. The capacity determined based on the new total load after deducting the load supplied by the generators. The safety margin used remains the same, at +40% of the total load power.

This calculation reduced the maximum power capacity of the PLTU to only about 41MW, while the other power plants have its power capacity calculated using the same power ratio and power factor as before.

Using this modified power capacity, the simulation now gives the following results. All power plants now have positive active power values, meaning they all function as suppliers, with no further absorption occurring.

Meanwhile, the load voltage magnitude has not changed significantly, reaching a maximum of 1.0235pu for on-grid and 1.0213pu for off-grid. This indicates that the reduction in power capacity at each power plant has been appropriately implemented.

4.6 Solar Power Plant and Generator Set as Subsidiary Power Supply

Based on the obtained results, the addition of Solar Power Plants (PLTS) and generator sets (genset) to supply power to the specified load reduces the total power that needs to be supplied by the PLTP, PLTU, PLTA, and PLTB power plants. In the load flow analysis, the active power from PLTP (and PLTA at night) is negative. This occurs because PLTP (and PLTA) are swing generators capable of absorbing power in case of an overload. In this case, the power supplied by the PV generator is excessive, so it needs to be absorbed by the swing generator. This absorption has a positive impact on the overall system, preventing overloads that could have adverse effects.

The value in the Vpu section increases compared to the normal condition (without special or emergency situations). This is due to the power from the generation plants already supplying sufficient power to the load. The maximum Vpu value at the load is 1.0251, which occurs during nighttime for industry in combined circuit with the generator sets still connect to power plants. This value is quite good and normal, as a result of power absorption by the swing generator. The power absorption by the swing bus also helps prevent overvoltage.

In addition to the above, it can be observed that the power absorption by PLTA is greater than that of PLTP. This may be due to the proximity of PLTA to the load compared to PLTP. A key point to note is that the power absorption by PLTA exceeds its maximum capacity, which could damage the machinery in the long term. Potential solutions to address this issue include rebalancing the load and generation plants, increasing generator capacity, or improving the system control between plants.

Therefore, an additional design modification was implemented in the system to ensure that the output power from the swing generator does not exceed its capacity. Furthermore, the swing generator was also constrained to prevent it from operating at negative power levels. In this design, an additional load (dump load) is introduced to operate when the power supply from the PV generator exceeds the demand (i.e., supply > load). The power absorbed by the dump load is 75 MW.

Based on the simulation results, the active power output of the generator remains non-negative throughout the operation. This outcome satisfies the additional design criteria.

In practical implementation, the dump load can take the form of water heaters, electric heaters, resistive fans (typically in PV systems), and other devices capable of absorbing excess energy. Moreover, the dump load can also represent a grid-connected system, allowing the excess power from the generator to be exported to the grid, thereby eliminating the need for absorption by the swing generator.

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