Module #3 – Big Project

EL3017 – Electrical Power Systems

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# Introduction (*Heading 1*)

In this module, the design and simulation of an electric power system to meet the load requirements in a city by considering various predetermined parameters and constraints are carried out. Experiments in this module are conducted using MATLAB Simulink and SimPowerSystems™ to model distribution networks, analyse load flow, and evaluate system performance under normal and emergency conditions. This module aims to understand the characteristics of power plants (PLTP, PLTU, PLTA, PLTB), load distribution based on operational time, and optimisation techniques to maintain voltage stability and power factor in the designed system.

The focus of experiments in this module includes load scheduling, determination of line and transformer capacity, and symmetrical disturbance analysis to anticipate disturbances in the system. In addition, students will design generation operation strategies in various scenarios, especially emergency conditions when only priority loads are supplied. Through this module, students are expected to be able to understand the principles of power system planning, apply power flow studies, and develop simulation-based solutions as a provision in solving engineering problems in the real world, especially regarding electric power systems.

# Theoretical Foundations

## Load Flow Analysis

Load flow analysis, commonly known as load flow study, is an important calculation in the planning, economic scheduling, and control of an existing power system as well as its future expansion planning, [1]. This study aims to determine the magnitude and phase angle of the voltage at each bus as well as the flow of active and reactive power on each line in the power system under steady state operating conditions. Information obtained from power flow studies is needed to evaluate power system performance and analyse generation or loading conditions. The fundamental problem solved is to find the power flow on each line and transformer in the network, as well as the voltage magnitude and phase angle on each busbar after the power consumption data at load points and power production on the generator side are known.

At each bus in the power system, there are four main quantities:

1. Active power (P) with units of Megawatts (MW).
2. Reactive power (Q) with units of Megavolt-Ampere-Reactive (MVAR).
3. Voltage scalar price (∣V∣).
4. Voltage phase angle (θ).

In power flow studies, at each bus only two of these four quantities are determined, while the other two quantities are the result of calculations, [3].

The relationship between power, voltage, and current in complex form can be expressed as:

where S is the apparent (complex) power, V is the complex voltage, and I∗ is the complex current conjugate.

In power system analysis, busbars are classified into three types based on known quantities:

1. Slack Bus (Swing Bus or Reference Bus): On this bus, the voltage magnitude (∣V∣) and voltage phase angle (θ) are specified. The slack bus serves as a system balancer that supplies the deficiency or absorbs the excess active power (P) and reactive power (Q), including the power losses on the transmission line, because these losses are only known after the power flow solution is obtained.
2. Generator Bus (PV Bus or Voltage Controlled Bus): On this bus, the active power (P) and voltage scalar price (∣V∣) are determined. The reactive power (Q) and voltage phase angle (θ) are calculated. This bus usually represents the generator terminal that controls the voltage on the bus.
3. Load Bus (PQ Bus or Load Bus): On this bus, the active power (P) and reactive power (Q) consumed by the load are determined (usually a negative value in the power flow equation because power flows out of the bus). The voltage scalar price (∣V∣) and voltage phase angle (θ) are calculated.

## Short Circuit

Short circuit is a condition in an electrical circuit in which electric current flows through the path with the least resistance or electric current flows on an unwanted and shorter path, instead of following the proper circuit path [4]. In the study of short circuit analysis, changes in the magnitude of currents flowing through the channels in the power system are observed when a short circuit fault occurs until the current reaches its steady state [1].

Short circuit analysis studies are important for designing protection systems that can detect, disconnect, and isolate disturbances to ensure that the power system can overcome disturbances safely without damaging equipment or endangering human safety. The way to deal with short circuit events that occur in a power system is to disconnect the circuit when a fault occurs and isolate the fault as quickly as possible. This is done to reduce major damage to equipment. There are several devices that can be used such as:

1. Circuit breakers to break the current during a fault.
2. Protection relays to detect faults more quickly.
3. Fuses for additional protection.
4. Lighting Power Protection Devices to protect the system from lightning strikes and voltage surges.

## Faults

### Symmetrical Fault

Symmetrical fault is a fault in which all phases are short-circuited with each other, so that this type of fault is balanced in the sense that the system remains symmetrical or it can be said that the channels shift at the same angle (i.e. 120° on a three-phase line), [5]. Symmetrical faults are usually caused by extreme conditions or serious damage in the power system, such as crates striking directly into transmission lines, major damage to equipment such as transformers or generators, and mechanical accidents such as falling poles or cables touching each other between phases. The most common type of symmetrical faults is L-L-L fault (three-phase fault). Although rare, this fault is among the most severe because it produces the largest short circuit current, [6].

### Unsymmetrical Fault

Unsymmetrical faults are faults that only affect one or two phases in the power system, thus causing imbalance in the three-phase line, [7].

Types of unsymmetrical faults:

#### Single Line-to-Ground (L - G) Fault

A single phase to ground fault occurs when one conductor touches the ground directly, for example due to a broken cable and falls to the ground.

#### Line-to-Line (L - L) Fault

This inter-phase fault occurs when two conductors touch each other, usually due to strong winds or extreme environmental conditions.

#### Double Line-to-Ground (L - L - G) Fault

In this type of fault, two conductors (phases) come into contact with the ground simultaneously, either directly or through a conducting medium such as a tree, water, or metal structure.

# Considerations and Design

The design of this power system incorporates several critical constraints and operational assumptions to ensure realistic and efficient performance. The system must supply four distinct load categories: household, industrial, priority (e.g., hospitals), and public facilities (e.g., streetlights). Within the household sector, five residential communities are defined, with a fixed distribution ratio of 4:8:12:2:1. This ratio determines the proportional allocation of power capacity to each community while accounting for additional demands from priority and public loads.

To simulate real-world conditions, the system operates under three daily demand scenarios:

Daytime (05:00–17:00): Commercial loads (e.g., malls) are active, while residential cooling loads (e.g., air conditioners) are inactive.

Evening (17:00–22:00): Lighting and residential loads peak, but commercial loads decrease.

Night (22:00–05:00): Industrial and priority loads dominate, with limited residential activity.

These scenarios impose dynamic constraints on generator scheduling, transformer capacity, and transmission line stability. The system relies on four generators with distinct roles:

Two swing generators: Adjust output to balance demand (e.g., PLTP, PLTA).

Two PV generators: Operate at fixed capacity (e.g., PLTU, PLTB), with one restricted to nighttime use.

The network is divided into four geographic sectors, each serviced by a substation that steps down transmission voltage (70 kV) to distribution levels (20 kV or 380 V). Transmission lines interconnect substations and generators, with parameters (e.g., impedance, length) tailored to their distances (e.g., 5–100 km). Key assumptions include:

Voltage stability: ≥0.96 pu for household/public loads, ≥0.98 pu for industrial loads.

Power factor: >0.85 for industrial loads, maintained via capacitor banks.

Figure 1 illustrates the finalized system topology, integrating these constraints to ensure reliable power delivery across all scenarios.

## Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

## Units

* Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as “3.5-inch disk drive”.
* Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
* Do not mix complete spellings and abbreviations of units: “Wb/m2” or “webers per square meter”, not “webers/m2”. Spell out units when they appear in text: “. . . a few henries”, not “. . . a few H”.

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Number equations consecutively. Equation numbers, within parentheses, are to position flush right, as in (1), using a right tab stop. To make your equations more compact, you may use the solidus ( / ), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

*a**b* 

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## Some Common Mistakes

* The word “data” is plural, not singular.
* The subscript for the permeability of vacuum **0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o”.
* In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
* A graph within a graph is an “inset”, not an “insert”. The word alternatively is preferred to the word “alternately” (unless you really mean something that alternates).
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* In your paper title, if the words “that uses” can accurately replace the word “using”, capitalize the “u”; if not, keep using lower-cased.
* Be aware of the different meanings of the homophones “affect” and “effect”, “complement” and “compliment”, “discreet” and “discrete”, “principal” and “principle”.
* Do not confuse “imply” and “infer”.
* The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
* There is no period after the “et” in the Latin abbreviation “et al.”.
* The abbreviation “i.e.” means “that is”, and the abbreviation “e.g.” means “for example”.

An excellent style manual for science writers is [7].

# Analysis and Testing

This section presents the results of the analysis and testing of the power system, organized into several subsection. Each subsection focuses on specific component of the power system relevant to the analysis being discussed.

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#### Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation “Fig. 1”, even at the beginning of a sentence.

1. Table Type Styles

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1. Sample of a Table footnote. (*Table footnote*)
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The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

##### References

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Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

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