전력시스템 해석 및 설계

제 1 장
– Introduction
목차

1.1 History of Electric Power Systems
1.2 Present and Future Trends
1.3 Electric Utility Industry Structure
1.4 Computers in Power System Engineering
1.5 PowerWorld Simulator
1.1 History of Electric Power Systems

1.1 History of Electric Power Systems

- Steam turbines: 85%
- Hydro turbines: 7%
- Gas turbines: peak load 대응

- Steam plants: coal, gas, oil, uranium
- Coal (50%), Nuclear (19%), Natural gas (19%), Hydro (3%), Oil (2%), Wind, Solar, Geothermal, Tidal - 2004년 기준
- 원자력 발전의 증가가 멈춘 이유
  (1) Rising construction costs
  (2) Licensing delays
  (3) Public opinion (safety and environmental issues)

Promising tech. : Nuclear fusion energy
  - 원료 : 중수소 (deuterium)
1.1 History of Electric Power Systems

◆ 주파수(frequency):
  - 60-Hz system: 미국, 캐나다, 일본, 브라질
  - 50-Hz system: 유럽, 러시아, 남아메리카, 인도, 일본

- 60-Hz system 의 장점:
- 50-Hz system 의 장점:
1.1 History of Electric Power Systems

- 1902~1972: 7%
- 1972~1980: 3.4%
- 1980~2000: 2.1%

**FIGURE 1.2**

- Increase in the size of generating units: Table 1.1

- Increase of transmission voltage: Table 1.2

1. 증대: 송전거리와 송전용량
2. 감소: 선로의 전압강하
3. 감소: 선로 손실
4. 절감: 송전 투자비와 운용비용
<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Transfer Limit (MVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>75</td>
</tr>
<tr>
<td>138</td>
<td>150</td>
</tr>
<tr>
<td>230</td>
<td>300</td>
</tr>
<tr>
<td>345</td>
<td>700</td>
</tr>
<tr>
<td>500</td>
<td>1400</td>
</tr>
</tbody>
</table>

Figure 2-85. Typical Transfer Limits
전압의 분류 (대한민국)

(1) 저압 (Low Voltage) : AC 600V 이하
DC 750V 이하

(2) 고압 (High Voltage) : AC 600 ~ 7000V
DC 750V 이상

(3) 특고압 (EHV, Extra-) : 7000V 이상

(4) 초고압 (UHV, Ultra-) : 345kV, 765kV

* 전압의 분류 (대한민국)

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Year of Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3</td>
<td>1893</td>
</tr>
<tr>
<td>44</td>
<td>1897</td>
</tr>
<tr>
<td>150</td>
<td>1913</td>
</tr>
<tr>
<td>165</td>
<td>1922</td>
</tr>
<tr>
<td>230</td>
<td>1923</td>
</tr>
<tr>
<td>287</td>
<td>1935</td>
</tr>
<tr>
<td>345</td>
<td>1953</td>
</tr>
<tr>
<td>500</td>
<td>1965</td>
</tr>
<tr>
<td>765</td>
<td>1969</td>
</tr>
</tbody>
</table>
Table 1.1-2 Standard Voltages

<table>
<thead>
<tr>
<th>North American Transmission (kV)</th>
<th>European Transmission (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>60</td>
</tr>
<tr>
<td>115</td>
<td>110</td>
</tr>
<tr>
<td>138</td>
<td>132</td>
</tr>
<tr>
<td>161</td>
<td>220</td>
</tr>
<tr>
<td>230</td>
<td>275</td>
</tr>
<tr>
<td>345</td>
<td>400</td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>735–765</td>
<td>765</td>
</tr>
<tr>
<td></td>
<td>1100 (not in general use)</td>
</tr>
</tbody>
</table>

Figure 1.1-3 Japanese transmission system (EPRI 2004).
Figure 1.1-4  Transmission infrastructure in China (EPRI 2004).
The technological developments in conjunction with ac transmission (pp14-15)

1. 현수 애자
2. 고속의 보호 계전 시스템
3. 고속의 초 고압 차단기
4. 초 고압 선로의 고속 재폐로
5. 초 고압 피뢰기(surge arrester)
6. 전력선 통신, 무선통신, 광통신
7. 절연협조
8. 에너지 감시제어 센터: 원방제어 및 데이터취득 (SCADA) 기능과 발전자동제어 (AGC)를 갖추고 중앙컴퓨터를 이용해서 발전, 송변전, 배전 등 전체시스템을 감시하고 제어
9. 배전자동화: 지리정보시스템 (GIS)과 결합하여 지역내 배전시스템의 각종 설비를 감시하고 제어
10. 디지털 계전기: 기존 단순한 기계식 계전기가 할 수 없었던 이벤트 감시/기록, 고장지점 찾기, 고장 해석, 자기 진단, 데이터 저장, 차단시 제어 등의 기능을 수행할 수 있다.
1. 현수 애자

Figure A3.2-8  275-kV transmission-line surge arresters (Courtesy Eskom and ABB).
Figure 2.3-8 500-kV line with three four-subconductor bundles (and inset).
Figure 2-83. Transmission Line Structures
2. 고속의 보호 계전 시스템

![Electromechanical, Solid State & Microprocessor Relays](image)
345kV 송전선로 보호배전반 (2008년 이전)
3. 고속의 초고압 차단기

Figure 2-58. Synchronizing System for a Substation Breaker
Power Circuit Breakers

- Waits for **current zero** to extinguish arc

- Typical **interrupting times** 3-8 cycles

- Attempts to prevent **arc re-ignition** (The interrupter must build up dielectric faster than the recovery voltage builds up)

- **Commutes plasma** by removing energy which is in the form of heat
Power Circuit Breakers

The ability of the breaker to interrupt fault current is determined by two things:

(1) the magnitude of the fault current

(2) the magnitude and rate of rise of the voltage across the contacts after the current goes out (both 60 hertz and transient voltages)
Interrupters

- Arcing Contacts and medium (oil or gas) flow

Axial Flow

Cross Flow
Oil Interrupters:

- Current zeros
- Recovery voltage

Explosion Pot

- Arc goes out
- t

Current zeros

Arc goes out
Types of Breakers:

1. Oil
2. Air blast
3. Air magnetic
4. SF6 gas
5. Vacuum
6. Others
Interrupters

(1) Oil
Oil Breaker (Westinghouse 345G)
Interrupters

(3) Air Magnetic

Magnetic Field

Insulating Fins

Arcing Contacts
Interrupters

(4) $\text{SF}_6$ Gas
Vacuum
Breaker Applications
Figure 2-89. Photograph of Circuit Breaker
There are many different types of circuit breakers including:

- Oil circuit breakers
- Air circuit breakers
- SF₆ gas circuit breakers
- Vacuum circuit breakers

Figure 2-88. Circuit Breaker Opening Process
Power Circuit Breaker Ratings

- A circuit breaker is a tie between two networks.
Fault: \( \text{faultV} = 0 \)

Breaker opens

2 per unit

Transient Recovery Voltage

\( \text{Fault} \)

\( \text{v} \)

\( \text{i} \)

\( \text{t} \)
Transient Recovery Voltage:

\[
TRV_{bus} = 1 - \frac{\cos t}{\sqrt{LC}}
\]

\[
TRV_{line} = 1 - \frac{\cos t}{\sqrt{LC}}
\]

Total TRV = bus - line

Time in hundreds of microseconds

Initial Rate of rise

Crest recovery voltage

V
4. 초 고압 선로의 고속 재폐로
5. 피뢰기 (surge arrester)

Figure A3.2-8 275-kV transmission-line surge arresters (Courtesy Eskom and ABB).

Figure 3.2-9 275-kV gapless arresters on an Eskom line (Courtesy Eskom and NGK).
6. 전력선 통신, 무선통신, 광통신
7. 절연협조

**WHAT IS INSULATION COORDINATION?**

A DEFINITION FROM C62.22 -

**INSULATION COORDINATION** - THE SELECTION OF INSULATION STRENGTH CONSISTENT WITH EXPECTED OVER VOLTAGES [WITH OR WITHOUT OVERVOLTAGE PROTECTION] TO OBTAIN AN ACCEPTABLE RISK OF FAILURE

FUNDAMENTAL GOAL OF INSULATION COORDINATION -
- TO SELECT MINIMUM ACCEPTABLE INSULATION STRENGTH, THAT IS
  - MINIMUM AIR CLEARANCES
  - MINIMUM SOLID / LIQUID INSULATION

DETERMINE MAXIMUM ELECTRIC STRESS [OVER VOLTAGE OR OVER CURRENT ] AND COMPARE WITH INSULATION STRENGTH

IF STRESS EXCEEDS STRENGTH DO SOMETHING TO RELIEVE STRESS OR INCREASE STRENGTH

OVERALL OBJECTIVE - TO SPECIFY MINIMUM INSULATION AND PROTECTIVE EQUIPMENT [REDUCE COSTS], WHICH IS REQUIRED TO WITHSTAND VOLTAGES IMPOSED ON THE INSULATION, FOR THE SPECIFIC DEGREE OF RELIABILITY DESIRED
Figure 3.1-1 Insulation coordination process.
8. 에너지 감시제어 센터
9. 배전자동화
10. 디지털 계전기

10.6.2 배전용 보호 계전기 (2)

- 과전류 계전기(Overcurrent relay)
  - (그림 10-24) 반한시 과전류 계전기에 대한 시간-과전류의 일반적인 동작 특성을 나타낸 것
    - 반한시 특성: 전류가 많이 흐르면 흐름속도, 동작시간은 더욱 깊어 지는 것

[그림 10-25 과전류 계전기]
디지털 계전기(Digital Relay)의 구성

그림 10-23 디지털 계전기의 기능적 구성도

1. Analog Input Subsystem
   : 대부분 3 ~ 30개의 입력을 받으며, CT, PT에 의해 입력됨
2. Digital Input Subsystem
   : 접점의 위치나 계전기가 요구하는 전압 측정 정보가 입력되며, 주로 5~10개의 입력신호가 존재 이 신호는 버퍼에 저장되어야 함
3. Digital Output Subsystem
   : 약 10개의 디지털 신호로서 계전기의 출력
4. Data Scratchpad와 Historical data file
   : 입력된 아날로그 데이터는 A/D 변환을 거쳐 샘플링되며, CPU에서 사용 될 수 있도록 RAM에 저장 과도상태의 데이터는 historical data file에 저장
5. Digital Filter
   : 입력되는 아날로그 데이터에 포함된 노이즈를 제거하는데 사용
6. Relay Logic
   : 입력값과 내부에서 계산된 값들을 사용하여 요구되는 보호기능을 구현
<table>
<thead>
<tr>
<th>IEEE Number</th>
<th>Device</th>
<th>Relay Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Distance Relay</td>
<td>Requires a combination of high current and low voltage to operate. The various zones of the distance scheme (Z1, Z2, etc.) assist with determining the location of the fault.</td>
</tr>
<tr>
<td>25</td>
<td>Synchronizing Relay</td>
<td>Checks voltage magnitude, phase angle, and frequency to verify synchronism across a circuit breaker before allowing a close.</td>
</tr>
<tr>
<td>27</td>
<td>Undervoltage Relay</td>
<td>Operates when voltage falls below a set value.</td>
</tr>
<tr>
<td>49</td>
<td>Thermal Relay</td>
<td>Operates when the temperature (usually a winding) exceeds set limits.</td>
</tr>
<tr>
<td>50</td>
<td>Instantaneous Overcurrent</td>
<td>Operates with no time delay when current rises above a set level.</td>
</tr>
<tr>
<td>51</td>
<td>Time Overcurrent</td>
<td>Operates on a time-delayed basis depending on the amount of current above a set level.</td>
</tr>
<tr>
<td>52</td>
<td>Circuit Breaker</td>
<td>Circuit Breaker</td>
</tr>
<tr>
<td>59</td>
<td>Overvoltage Relay</td>
<td>Operates when voltage exceeds a set limit.</td>
</tr>
<tr>
<td>63</td>
<td>Pressure Relay</td>
<td>Operates on low or high pressure of a liquid or gas (oil or SF₆) or on a rate-of-change of pressure (sudden pressure).</td>
</tr>
<tr>
<td>67</td>
<td>Directional Overcurrent</td>
<td>Operates if current is above a set value and flowing in the designated direction.</td>
</tr>
<tr>
<td>78</td>
<td>Out-of-Step</td>
<td>Detects loss of synchronism.</td>
</tr>
<tr>
<td>79</td>
<td>Reclosing Relay</td>
<td>Initiates an automatic closing of a circuit breaker following a trip condition.</td>
</tr>
<tr>
<td>81</td>
<td>Frequency Relay</td>
<td>Operates if frequency goes above or below a set limit.</td>
</tr>
<tr>
<td>86</td>
<td>Lockout Relay</td>
<td>An auxiliary relay that can perform many functions (including tripping of breakers) and prevents closing of circuit breakers until it is reset either by hand or electrically.</td>
</tr>
<tr>
<td>87</td>
<td>Differential Relay</td>
<td>Senses a difference in currents entering and leaving power system equipment.</td>
</tr>
<tr>
<td>94</td>
<td>Tripping Relay</td>
<td>Auxiliary relay which is activated by a protective relay and which initiates tripping of appropriate breakers.</td>
</tr>
</tbody>
</table>
1.1 History of Electric Power Systems

The incentives for increasing transmission voltage (p.14, 표 1.2)

1. Increases in transmission distance and transmission capacity
2. Smaller line-voltage drops
3. Reduced line losses
4. Reduced right-of-way requirements per MW transfer
5. Lower capital and operating costs of transmission
1.1 An interconnection systems

- An isolated systems

- An interconnected system (Fig. 1.3)

  - Advantages
  ① Maintaining continuity of service
  ② Increasing reliability
  ③ Reducing the total number of generators
  ④ Schedule power transfer

  - Disadvantages
  ① Increased fault currents
  ② Remote possibility of neighbor disturbance
1.1 An interconnection systems
1.2 Present and Future trends

◆ Electrification

The intensity of electricity = Electricity intensity
: electricity consumption per dollar of real GDP (ref. 4)

**FIGURE 1.2**

Growth of U.S. electric energy consumption
[1, 2, 3, 5] (H. M. Rustebakke et al.,
Electric Utility Systems Practice, 4th Ed. (New
York: Wiley, 1983).)
Electric energy generation in the United States, by principal fuel types [3, 5]

- **Several Trends**
  1. 석탄사용의 증가
  2. 천연가스 소비의 증가
  3. 원자력 소비의 감소
  4. 수력과 신재생의 증가
FIGURE 1.5

Installed generating capability in the United States by principal fuel types [3, 5]

- 965 GW (100%)
  - 314 GW (32.5%)
  - 433 GW (44.9%)
  - 100 GW (10.4%)
  - 118 GW (12.2%)
  
- 1,002 GW (100%)
  - 326 GW (32.5%)
  - 439 GW (43.8%)
  - 104 GW (10.4%)
  - 133 GW (13.3%)

- = coal
- = gas/oil
- = nuclear
- = hydro/other

Other includes IPPs, geothermal, wood, waste, wind, and solar energy
1.3 Electric utility industry structure

- **Vertically** integrated monopolies
- Horizontal structure

- Transmission Open Access(TOA)

- In the future, the retail structure of power distribution may resemble the existing structure of the telephone industry.
1.4 Computers in power system engineering

- Size 및 no. of interconnection 의 증가
- Planning for future expansion : many options

1) Power-flow programs
2) Stability programs
3) Short-circuits programs
4) Transients Programs
5) Other computer programs
1.5 PowerWorld Simulator

PowerWorld Simulator(*PowerWorld*) ver. 15

- www.powerworld.com/GloverSarmaOverbye
Two Bus Power System

Transmission Line

Bus 1 16.00 kV Bus 2

Generator

5.1 MW

Load

5.00 MW

15.75 kV
1.5 PowerWorld Simulator

Ex. 1.1 Introduction to PowerWorld Simulator

- **Edit mode** 일 경우

Two Bus Power System

- Bus 1: 16.00 kV, slack, 5.1 MW
- Bus 2: 15.75 kV, Load, 5.00 MW
- Transmission Line
1.5 PowerWorld Simulator

- Run mode 일 경우

- Two Bus Power System

- Bus 1: 16.00 kV, Generator: 5.1 MW
- Bus 2: 15.75 kV, Load: 5.00 MW
1.5 PowerWorld Simulator

Ex. 1.2 PowerWorld Simulator-Edit Mode

◆ Edit mode 일 경우

Two Bus Power System

Bus 1 16.00 kV Bus 2 15.75 kV
Bus 3 0.00 kV Load

Generator

5.1 MW

Transmission Line
1.5 PowerWorld Simulator

- **Run mode** 일 경우

![PowerWorld Simulator Image](image_url)
Bus 3 — 0.00 kV
1.5 PowerWorld Simulator

Ex. 1.3 PowerWorld Simulator

- **Edit mode 일 경우**

![PowerWorld Simulator Diagram]

The diagram shows a three-bus power system with the following specifications:

- **Bus 1**: 16.00 kV, 15.3 MW
- **Bus 2**: 15.66 kV
- **Bus 3**: 15.57 kV, 10.00 MW
- **Load**: 5.00 MW
1.5 PowerWorld Simulator

Ex. 1.3 PowerWorld Simulator-Run Mode

- **Run mode 일 경우**

![Three Bus Power System Diagram](image)
Questions

THANK YOU!