Preventing Large-Scale Emergencies in Modern Power Systems:
AI Approach

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The Sixteenth International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies

Valencia, Spain

March 8-12, 2026.

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Contents

- **Introduction**
- **Power System Security and Crisis Management**
- **Intelligent System for Clearing Overloads**
- **Intelligent System for Voltage Control**
- **The Security Alarm System**
- **Conclusions**

And then there was Darkness...

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Introduction

- Modern power systems are vulnerable to large-scale blackouts.

- During the past ten years events in Europe, North America and Asia have clearly demonstrated an increasing likelihood of large-scale blackouts. Blackouts now spread across borders.

- Huge economic losses, and disruptions in communication and transport, heating and cooling, water supply, emergency services, and financial trading.

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Introduction (cont.)

- Over the past decade, power industries worldwide have experienced two major changes: liberalization of the electricity market and the expansion of renewable energy.

- As wholesale markets have developed, congestion in the transmission network has increased significantly.

- In Europe, the United States and Australia there has been almost no investment in interregional transmission capacity since the early 1990s.

- Modern power systems have to operate close to their operational limits; this intensifies their vulnerability to blackouts.

Introduction (cont.)

- The increasing penetration of renewable energy has led to increasing dependency on the volatile nature of renewable energy sources.

- For example, wind farms in Eastern Germany during strong wind conditions can supply up to 12 GW, which is more than all of the coal- and gas-fired power plants in that part of the country combined. This situation presents significant risks to system stability even when demand is low.

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Power System Security and Crisis Management

- To keep the system in an operating condition when one or even a few components fail.

- Elements are operated within certain constraints and protected by automatic devices.

- Power system operators are required to take actions in emergency and abnormal conditions.

- There is a strong need for a decision support system.

But…

Intelligent System for Clearing Overloads

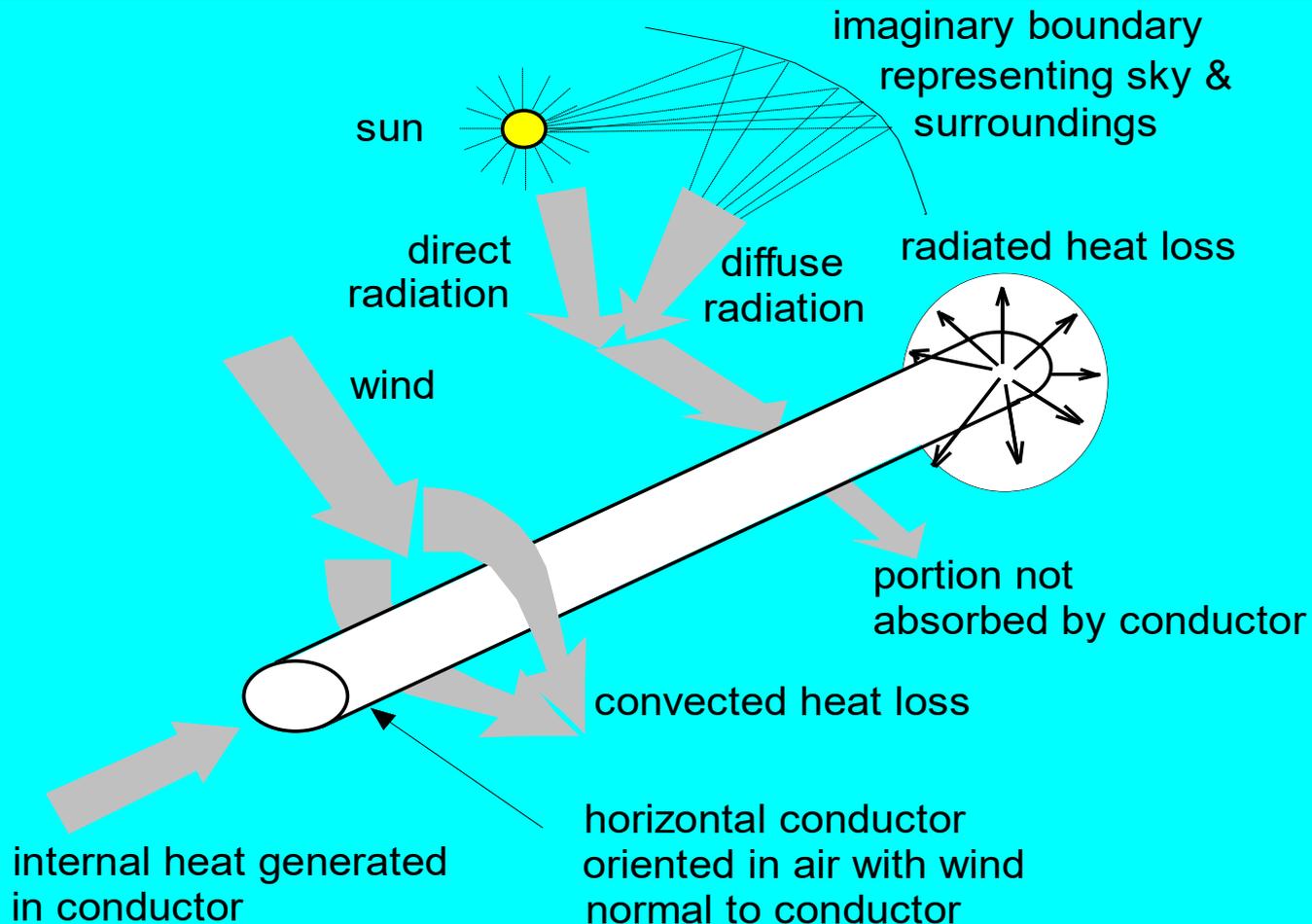## Short-time thermal rating

❑ Specified in terms of current or MVA at nominal voltage limits;

❑ Based on the conductor temperature which should be maintained within a safety limit;

❑ Applied under abnormal loading conditions.

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Loading capability of overhead conductors

Steady state thermal rating:
$$I = \left(\frac{q_c + q_r - q_s}{r} \right)^{0.5}$$

sun

imaginary boundary representing sky & surroundings

direct radiation

diffuse radiation

radiated heat loss

wind

portion not absorbed by conductor

convected heat loss

internal heat generated in conductor

horizontal conductor oriented in air with wind normal to conductor

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Intelligent System for Clearing Overloads

Objectives:

❑ to determine thermal ratings for overhead conductors during short-time overloads;

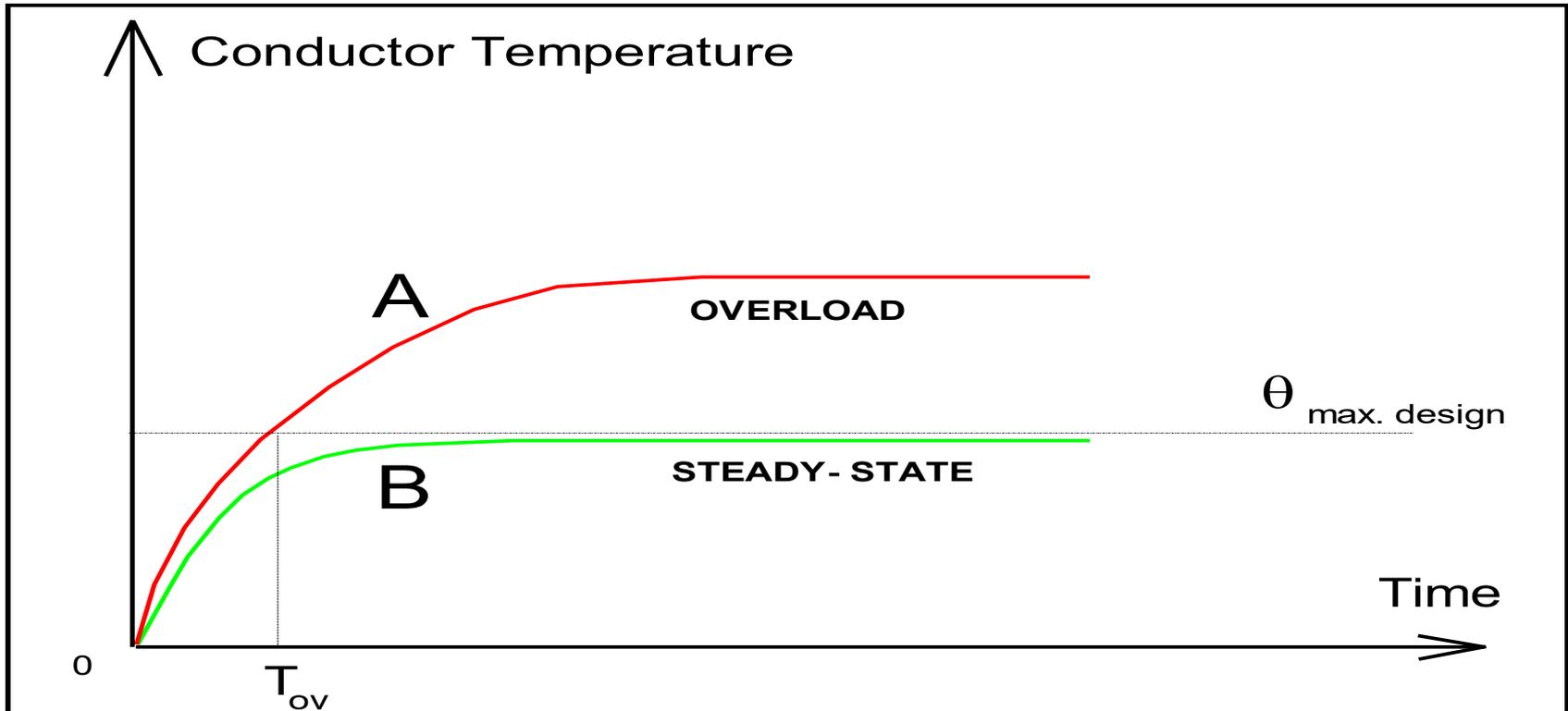❑ to determine the temperature rise due to an increase in load current.

Functions:

❑ to assist power system operators to determine limiting time a conductor can carry an increased current without the need to reduce loading or to reschedule generation.

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Conductor temperature rise during overload

Temperature - time characteristics

Conductor Temperature

A

OVERLOAD

$\theta_{\text{max. design}}$

STEADY - STATE

B

Time

0

T_{ov}
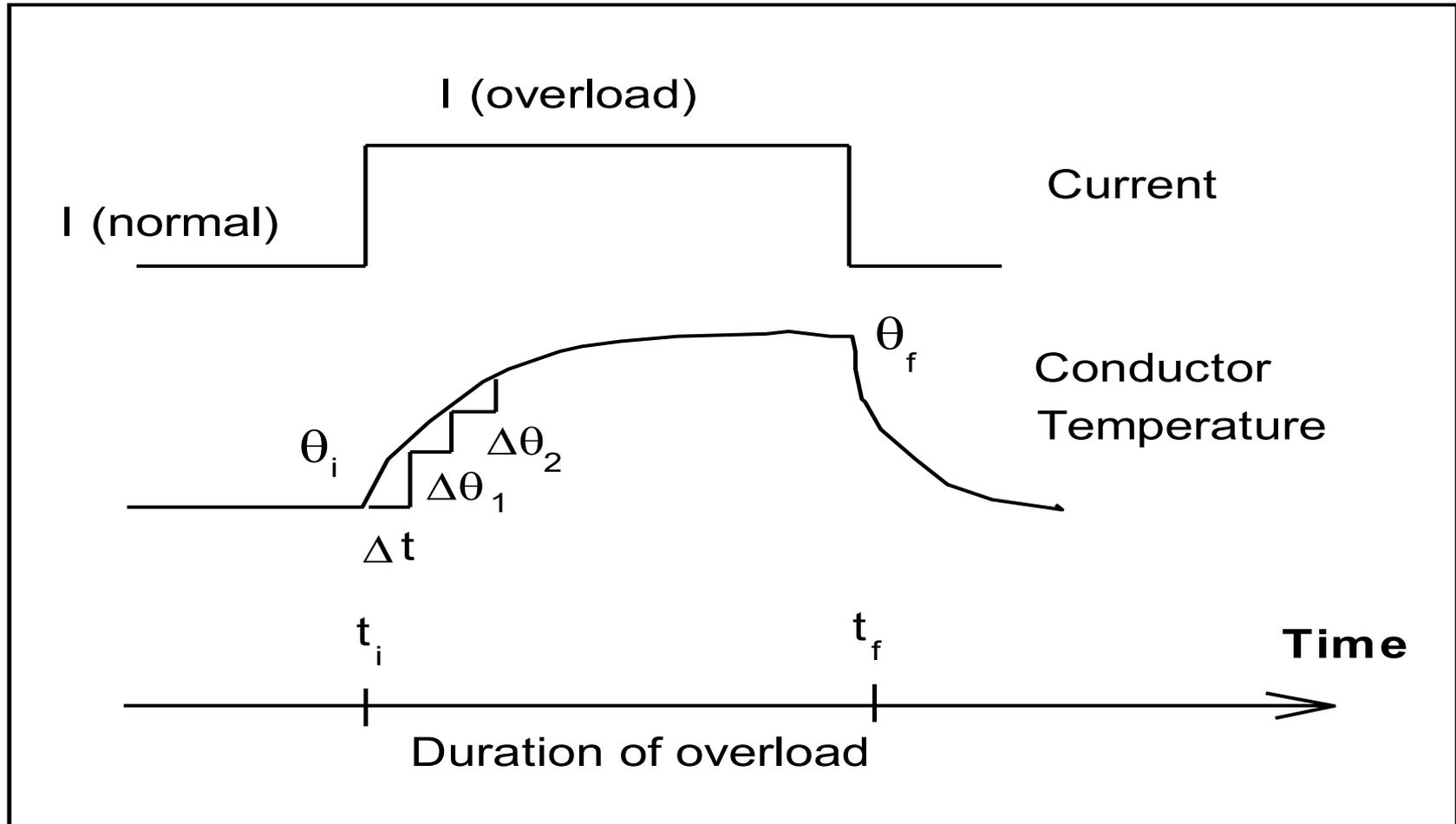
Time to reach max. design temperature:

For curve A: $_{ov}$ t = T

For curve B: t = infinity

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Short Time Ratings for Overhead Conductors
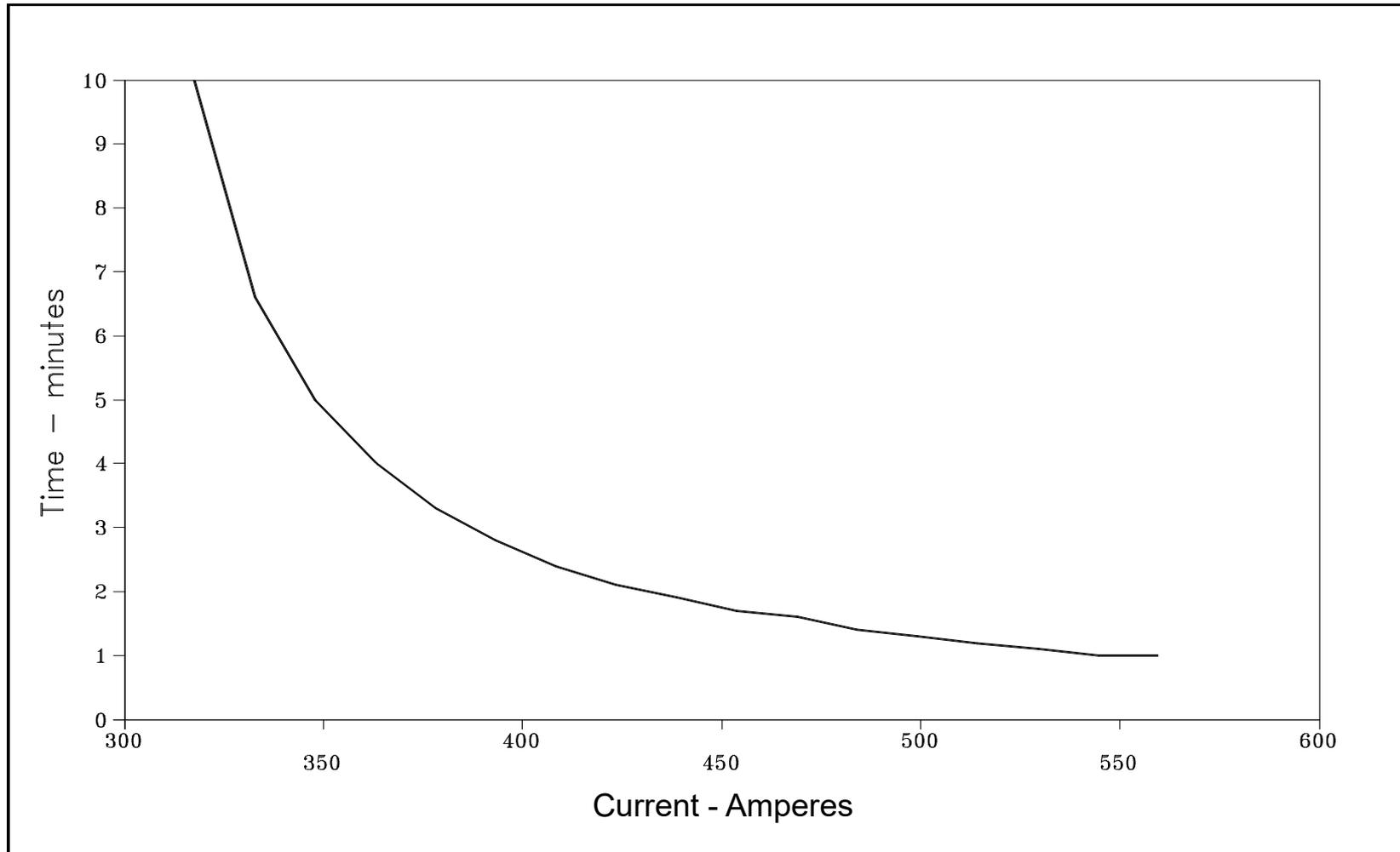
OUTDOOR TEST
Temperature - Time characteristic for conductor Drake

Drake 795 Mcm, 26x7 ACSR

Outdoor test:

wind = 26000 ft/hr, elevation = 2500 ft
ambient = 31 *C, emissivity = 0.75
initial current = 1000 A
initial temp = 65 *C
final current = 1950 A
final temp = 160 *C

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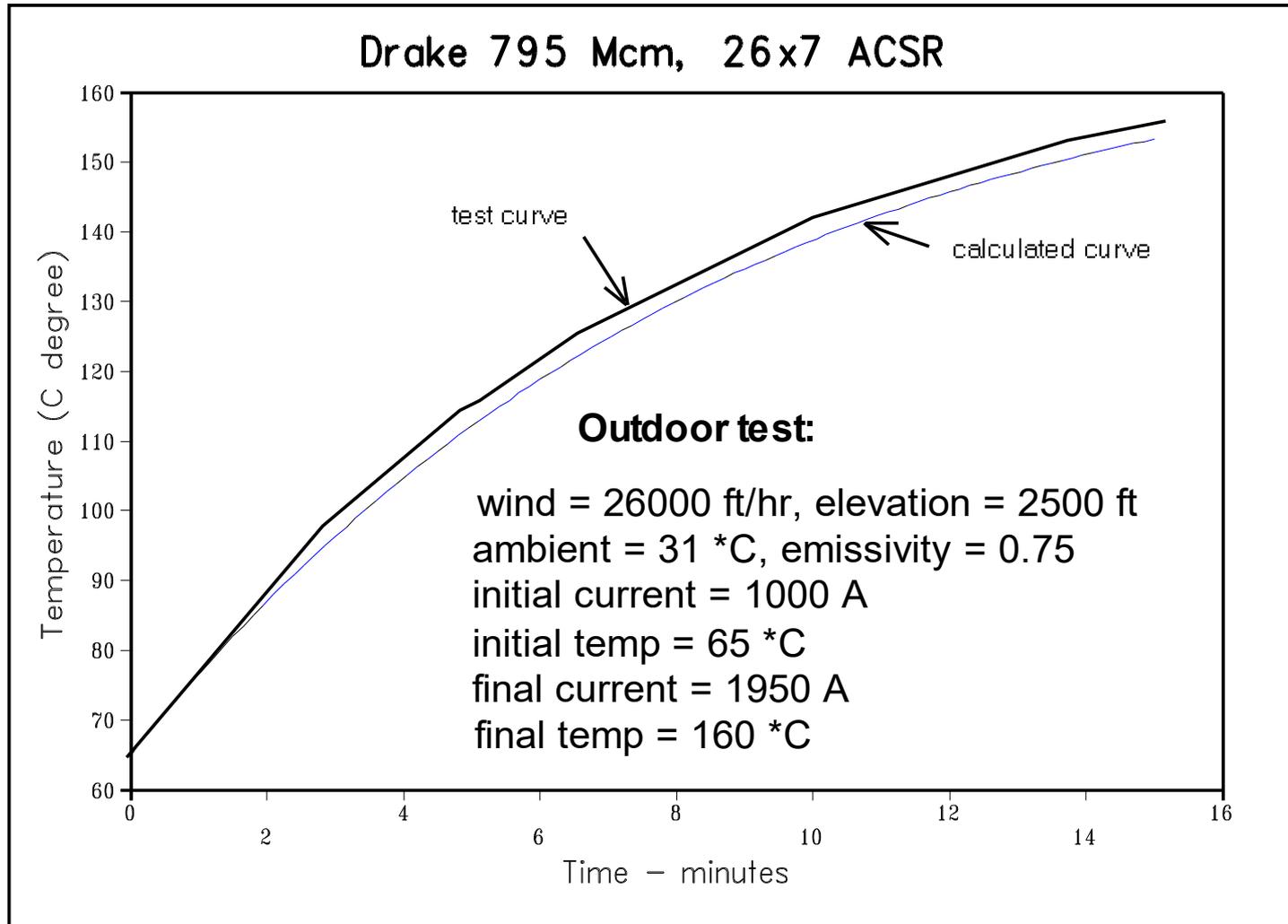
OUTDOOR TEST
Temperature - Time characteristic for conductor 19/.116" Cu

19/.116" Copper

Outdoor test: (without sun)

wind = 88500 ft/hr, elevation = 150 ft
ambient = 23 *C, emissivity = 0.23
initial current = 400 A
initial temp = 31.2 *C
final current = 550 A
final temp = 34 *C

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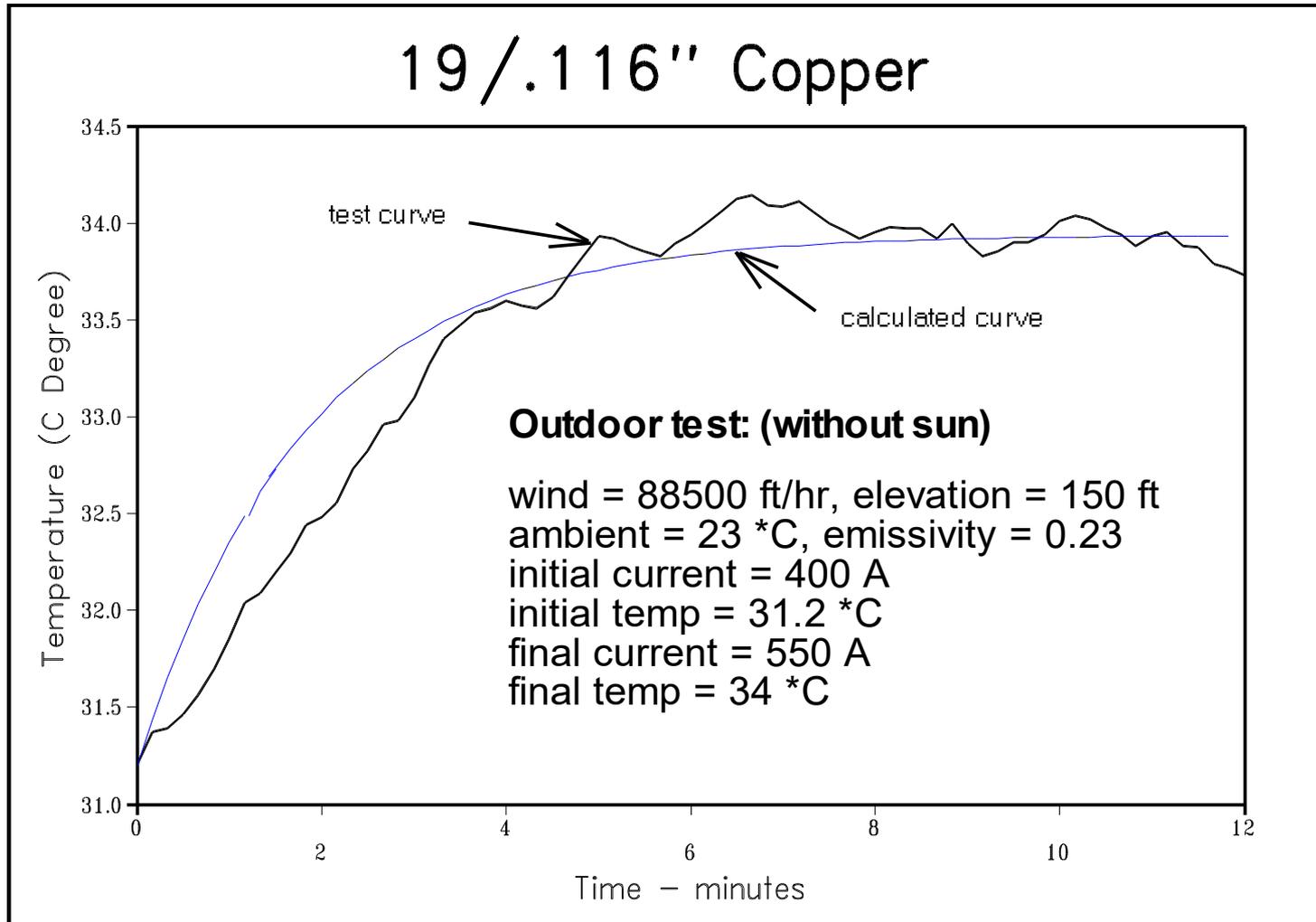
110 kV subsystem of the HEC system
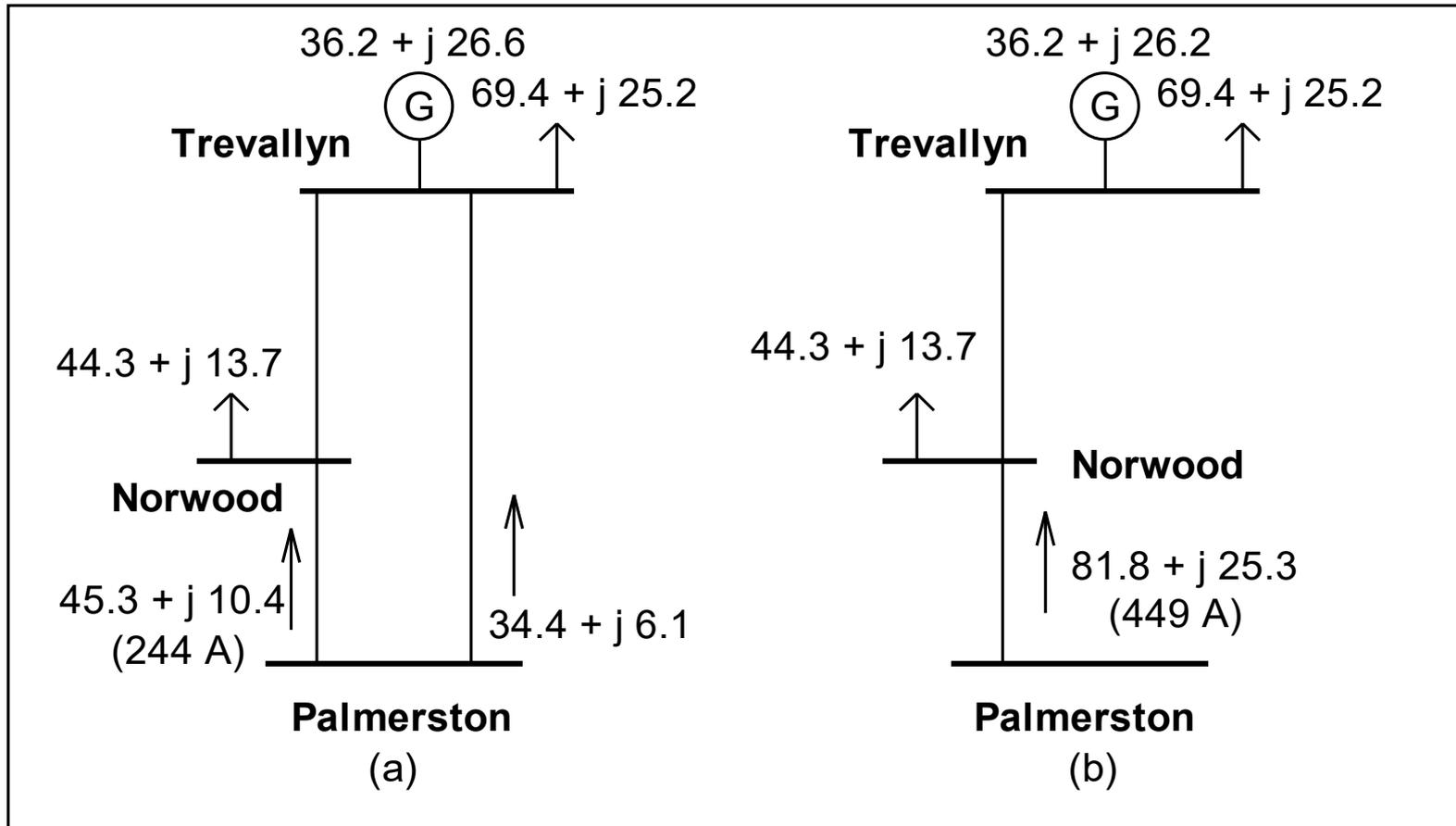
(a) Initial condition without outage;

(b) Final condition with outage of Palmerston - Trevallyn line

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Short-time rating for the Palmerston – Norwood line

Copper 19/0.116", 19 strands

conditions:

wind = 7200 ft/hr, elevation = 1640 ft
emissivity = 0.6, Idir = 93 W/sq. ft
ambient = 25 *C
initial current = 244 A
initial temp = 44.5 *C
final current = 449 A
final temp = 49 *C

1.9 min

449 A

Time – minutes

Current – Amperes

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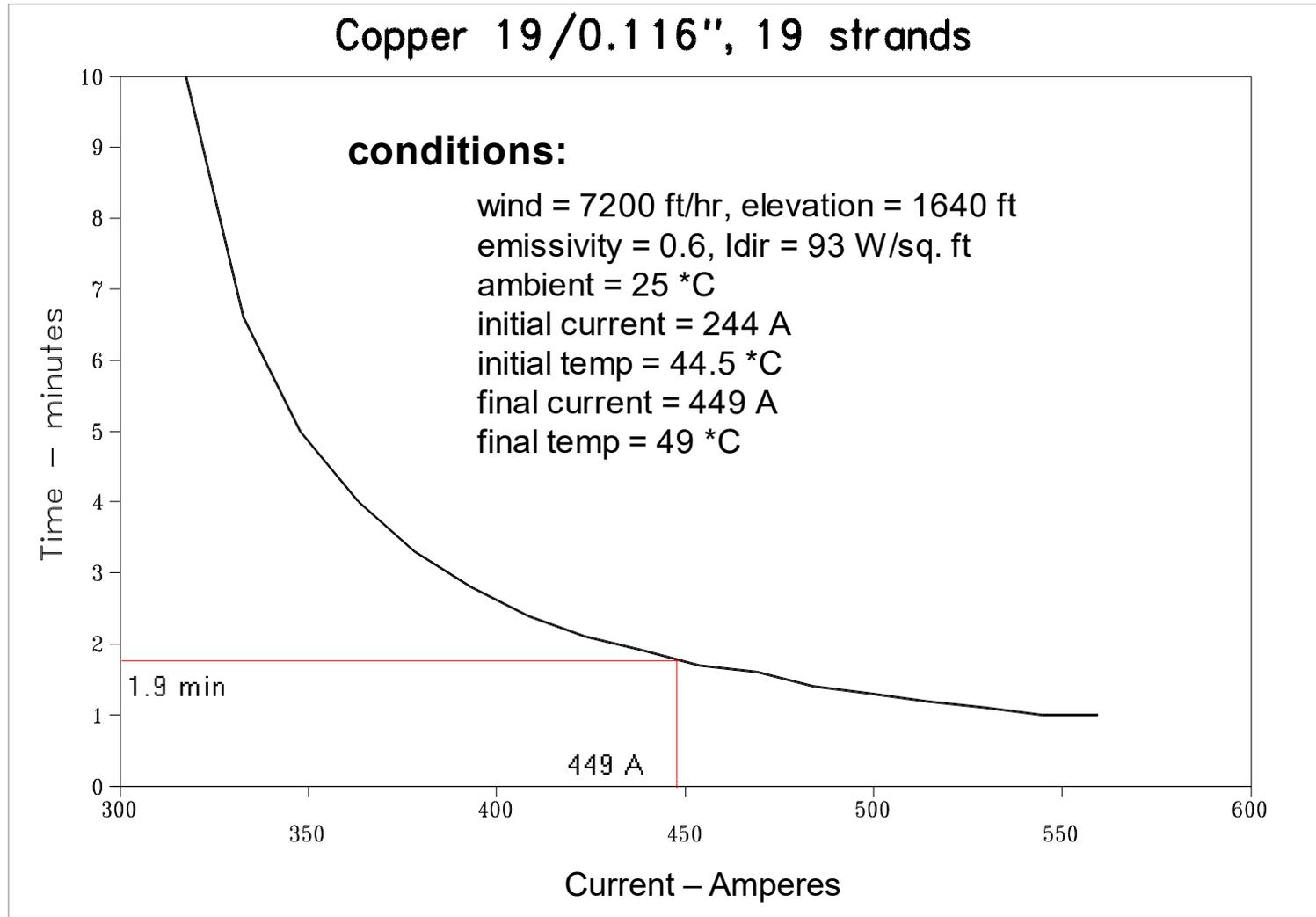
Calculation of sensitivity factors

Generation shift factors:

$$\alpha_{ij} = \frac{\Delta S_i}{\Delta P_{Gj}}$$

where ΔS_i is the change in power flow on element i when a change in generation, ΔP_{Gj}, occurs at bus j

Network reconfiguration factors:

$$\beta_{i,k} = \frac{\Delta S_i}{S_k^0}$$

where ΔS_i is the change in power flow on element i ; S_k^0 is the original flow on line k before it was opened

Load shedding factors:

$$\gamma_{ij} = \frac{\Delta S_i}{\Delta P_{Ln}}$$

where ΔS_i is the change in power flow on element i when a change in load, ΔP_{Ln}, occurs at bus n

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Intelligent System for Clearing Overloads

Database

- Short-term dynamic rating for each supervised line;

- Permissible overload duration as a load function;

- Upper and lower limits for each power station;

- Long-term ratings (emergency ratings) for each line;

- Guaranteed minimum load supply at each bus;

- Sensitivity factors for each supervised element and controller and the execution time for each controller.

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Intelligent System for Clearing Overloads
Numerical example: line 2-6 is overloaded

Six-bus power system

Case 1

- ❏ Bus 2: decrease generation on 5 MW;
- ❏ Bus 3: increase generation on 10 MW;
- ❏ Line 1-2: switch off

Case 2

- ❏ Bus 2: decrease generation on 5 MW;
- ❏ Bus 3: increase generation on 10 MW;
- ❏ Bus 6: shed load by 6.5 MW

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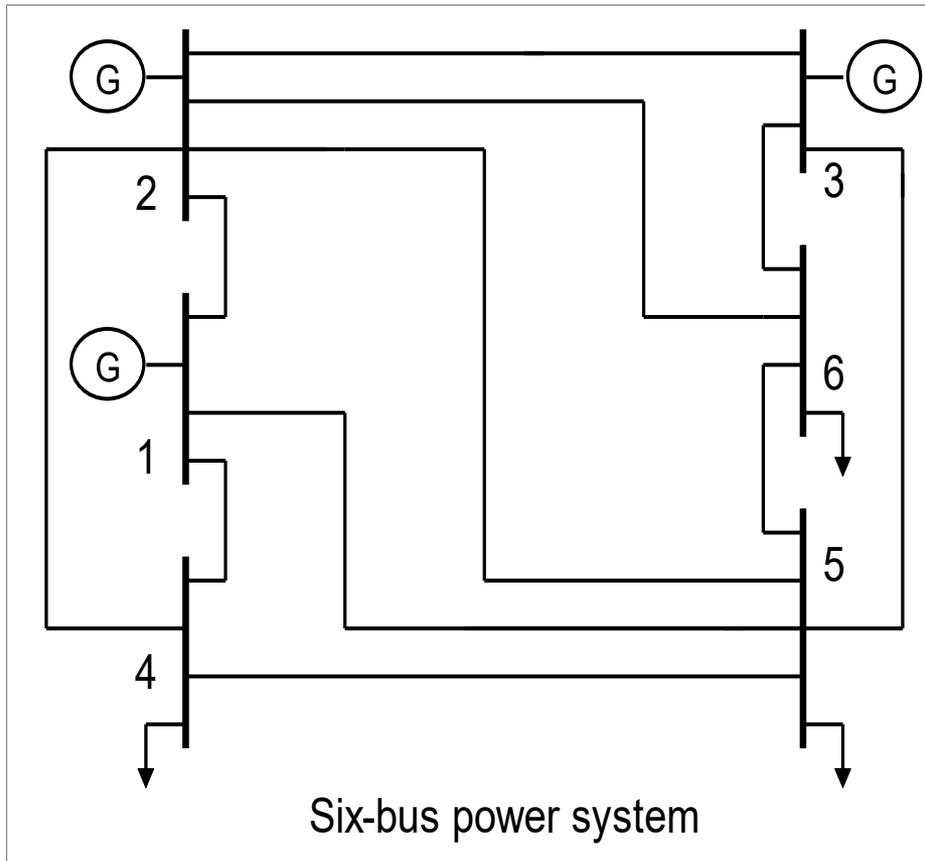
Intelligent System for Voltage Control

Objectives:

❑ to improve the computational performance by reducing the size of power system;

❑ to develop techniques for on-line voltage control in the case of contingency outages;

❑ to develop a prototype expert system

Functions:

❑ to identify voltage problems in the power system;

❑ to advise on appropriate remedial actions for voltage corrections;

❑ to determine locations and sizes of the additional VAR compensation.

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Intelligent System for Voltage Control
Database

- Upper and lower voltage limits at each bus;

- Upper and lower limits of each controller;

- Sensitivity factors for each load bus and each controller.

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Intelligent System for Voltage Control
Knowledge Base

Example of the rules implemented in the knowledge base:

- IF voltage on bus *i* is below the voltage limit

  THEN bus *i* is a low voltage problem bus

- IF bus *i* is a low voltage problem bus

  THEN include bus i in the low problem bus list

  AND arrange buses in voltage ascending order

- IF all voltage problem buses are determined

  THEN calculate the sensitivity factors

  AND select the most effective controller

Intelligent System for Voltage Control
Performance Evaluation

The IEEE 30-bus system

Intelligent System for Voltage Control
Performance Evaluation

The reduced IEEE 30-bus system

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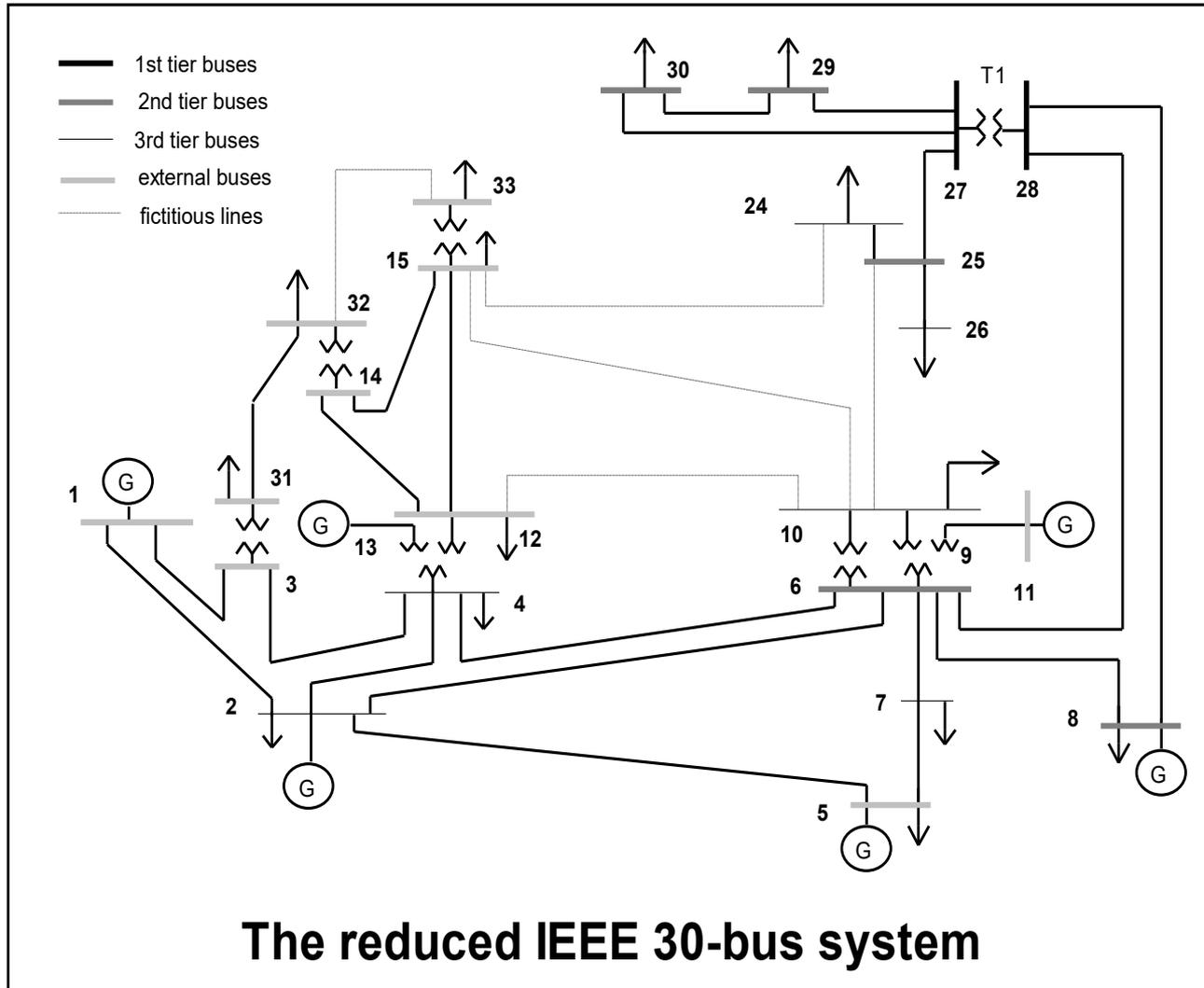
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Intelligent System for Voltage Control
Voltage Control Action Screen

Task 1:   Calculate the sensitivity factors

Task 2:   Detect voltage violations

   * number of voltage violations: 13
   * the lowest voltage occurs at bus: 30   { V(30) = 0.747 p.u. }

Task 3:   Correct voltage violations

   Action 1: select controller: transformer 6 - 9
        adjust its setting: 0.978 ⟶ 0.903   { V(30) = 0.769 p.u. }

   Action 2: select controller: transformer 6 - 10
        adjust its setting: 1.069 ⟶ 0.900   { V(30) = 0.810 p.u. }

   Action 3: select controller: transformer 4 - 12
        adjust its setting: 1.032 ⟶ 0.901   { V(30) = 0.839 p.u. }

   Action 4: select controller: generator 1
        adjust its setting: 1.050 ⟶ 1.060   { V(30) = 0.842 p.u. }

   Action 5: select controller: transformer 3 - 31
        adjust its setting: 1.069 ⟶ 1.000   { V(30) = 0.846 p.u. }

   Action 6: select controller: transformer 15 - 33
        adjust its setting: 0.950 ⟶ 1.094   { V(30) = 0.850 p.u. }

 ** This voltage violation cannot be corrected by the available controllers
   ** VAR compensation is required

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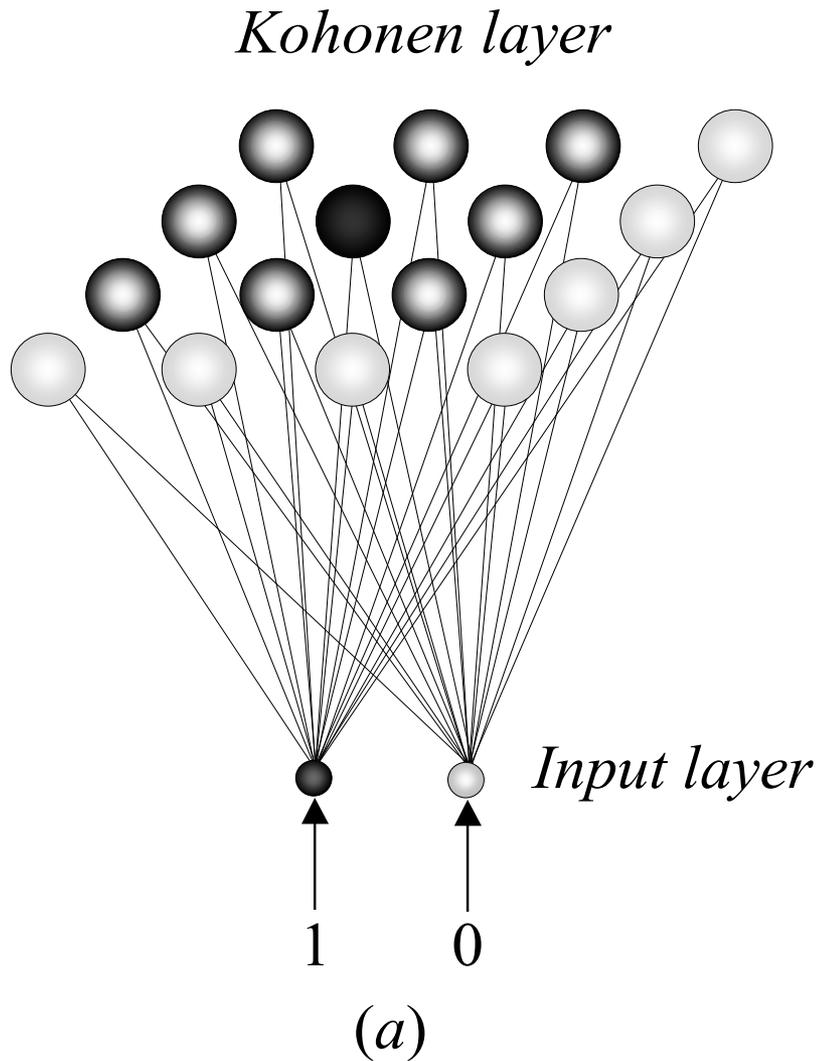**UNIVERSITY OF TASMANIA**

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The Kohonen neural network for detecting alarm states

❑   Practical experience demonstrates that most blackouts begin with a large disturbance (a disturbance, which may or may not cause cascading failures), which leads to a slow deterioration of the system conditions.

❑   The challenge is to identify pre-emergency conditions using enormous amounts of data with incomplete and distorted patterns. As all alarm states leading to large-scale blackouts are unique, there is no "algorithm" to identify such states.

Cluster analysis

❑ The term "cluster analysis" was first introduced over 70 years ago by Robert Tryon. Since then, cluster analysis has been successfully applied in many fields including medicine, archaeology, astronomy, etc.

❑ In clustering, there are no predefined classes – objects are grouped together only on the basis of their similarity. For this reason, clustering is often referred to as **unsupervised classification**.
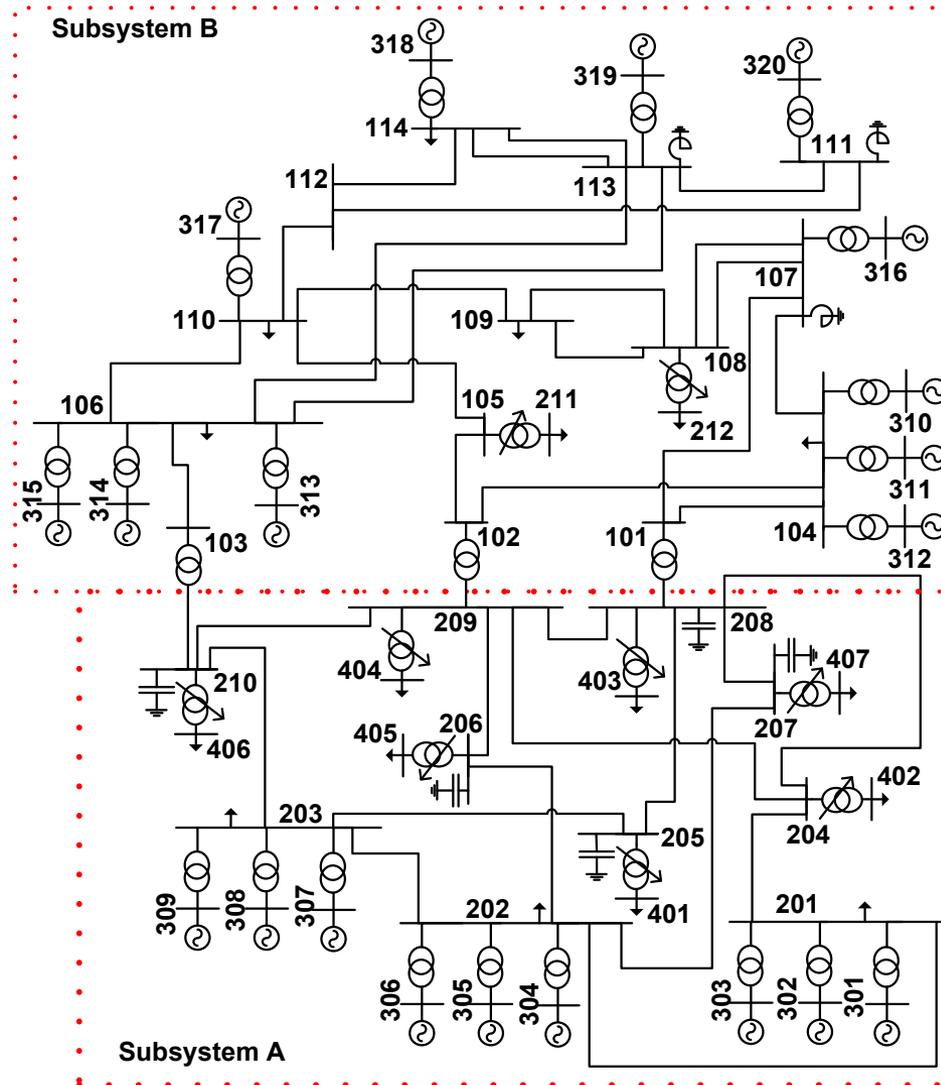
Feature-mapping Kohonen model

(a)   *(b)*

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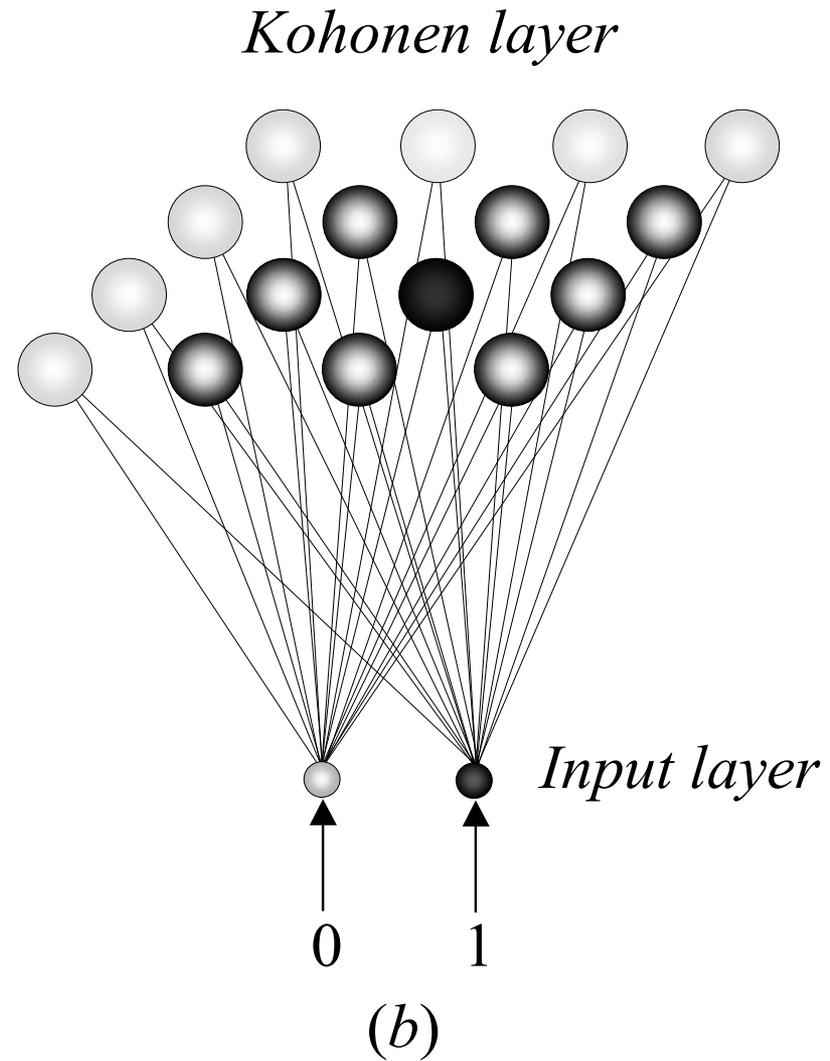
The security alarm system

❑ The Kohonen network-based security alarm system classifies the power system state to determine how dangerous the state is for the security of the entire system; and identify emergency conditions that may lead to large-scale emergencies and blackouts.

❑ The Kohonen network is trained off-line and used on-line to classify system operating states based on the patterns created in the off-line mode. Training examples are based on randomly generated events in a power system. The clusters are identified using test cases representing a set of normal and emergency conditions occurring.

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Kohonen network-based security alarm system

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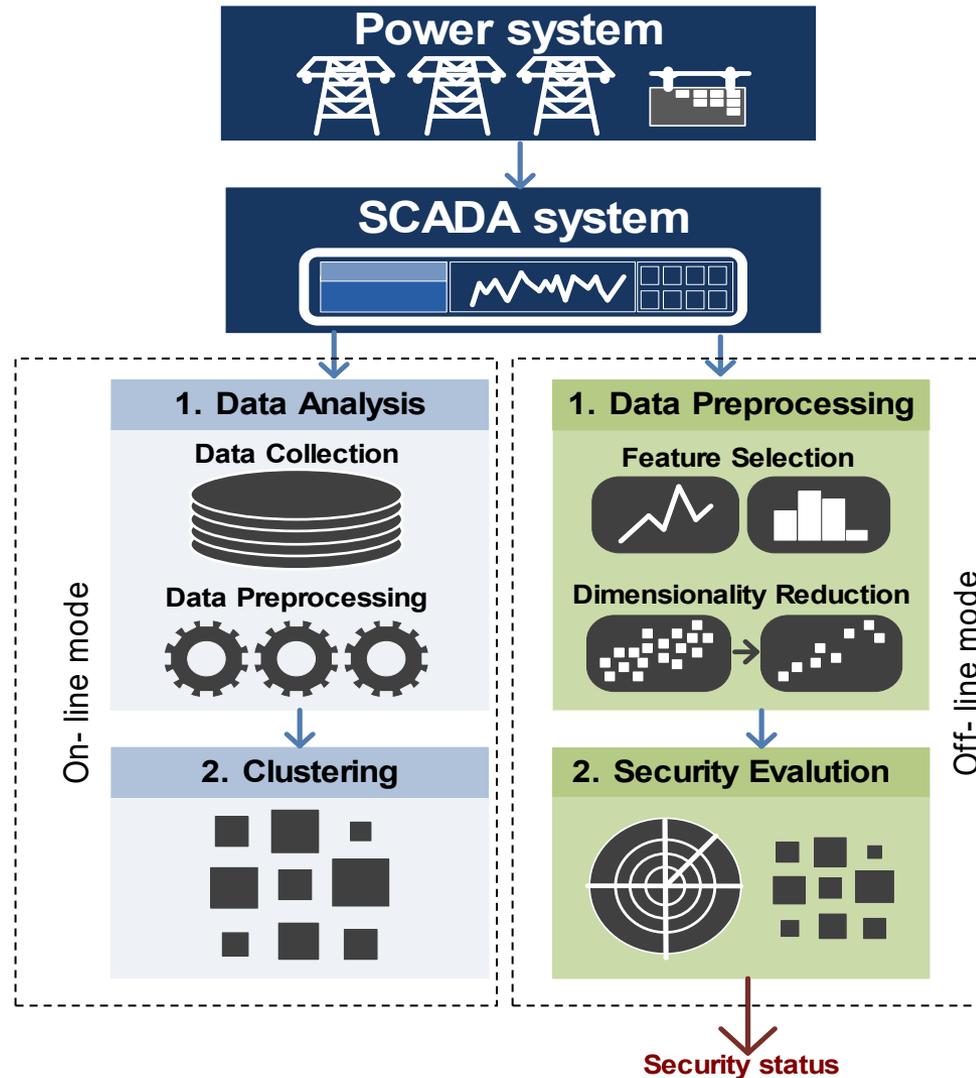
Case study: The 53-bus IEEE power system

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The system voltage profile
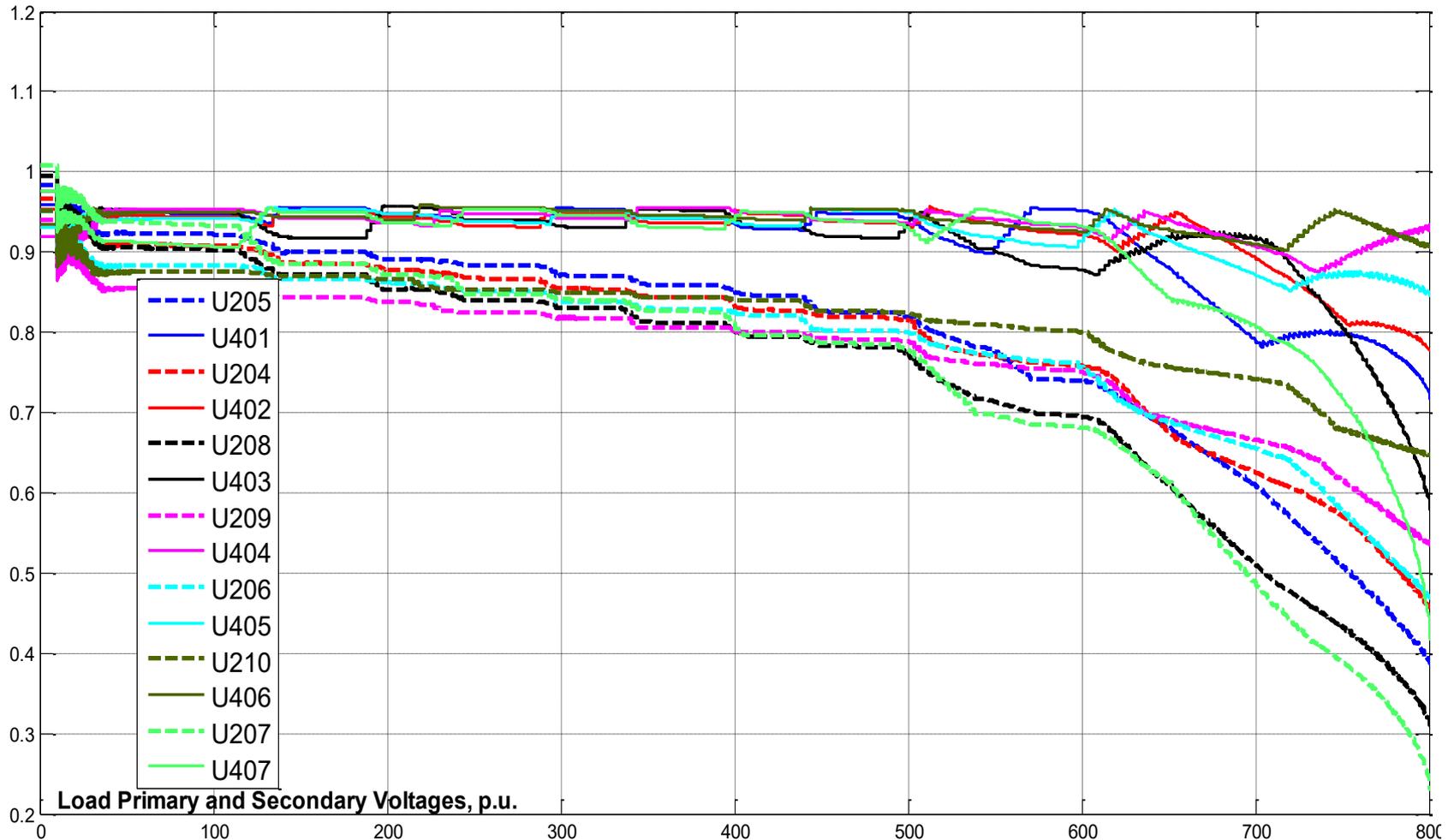
The Kohonen topological map
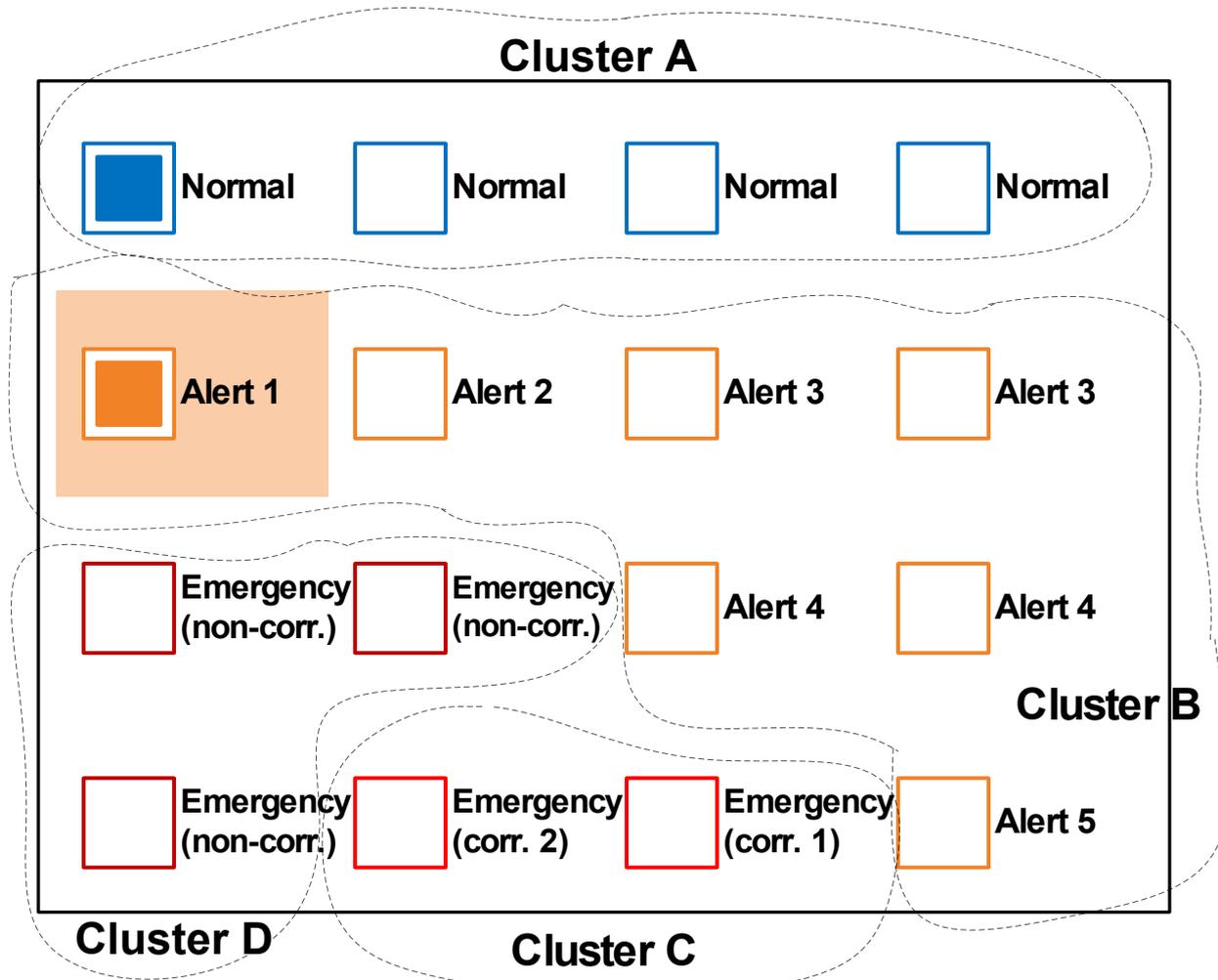
Operation of the Kohonen network
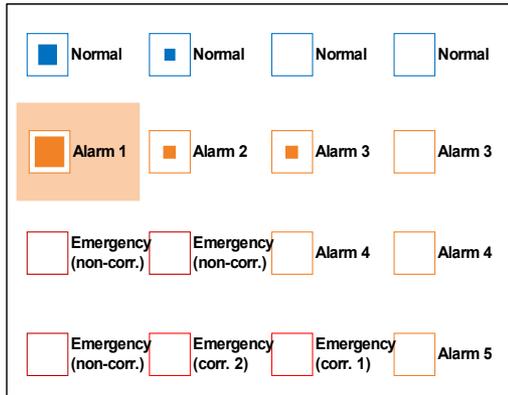
$T = 10$ s
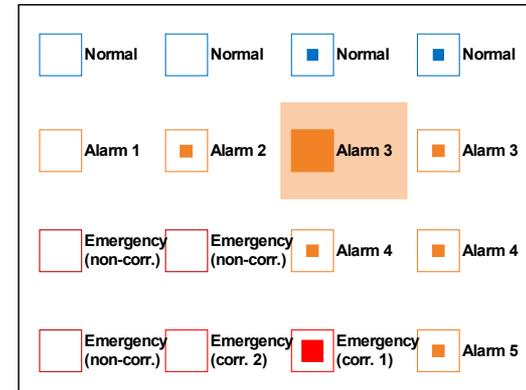
$T = 130.63$ s
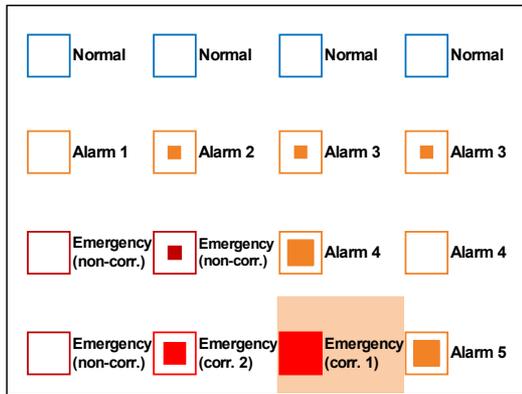
$T = 508.125$s
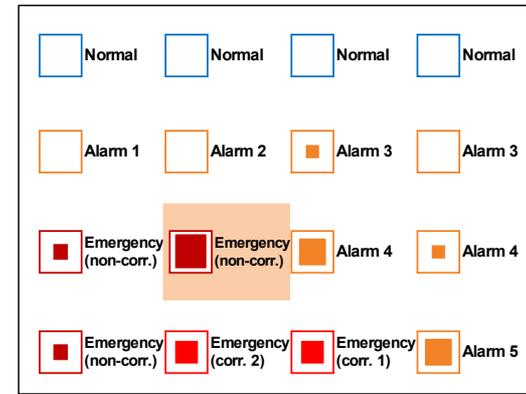
$T = 625$ s

Summary

❑ With rapidly increasing complexity of power grids in Europe, North America, Australia and Asia, liberalization of electricity markets and increasing penetration of renewable energy, the risk of large-scale emergencies and blackouts increases.

❑ This paper presented some experience obtained in the development of intelligent systems for preventing large-scale emergencies and blackouts in modern power systems. Prototype intelligent systems for clearing overloads, voltage control and detecting voltage instability problems on a large-scale have been developed and successfully evaluated.

Questions... if you dare...