Seminar on
African Electrical Interconnection

Module 5 - Power Systems Interconnection

Module 5 - Power Systems Interconnection

Contents

1) Reliability
2) System Planning Criteria
3) Power Transmission Technologies
4) System Studies
5) Transmission System Improvement
6) Advanced Transmission Technologies
7) Planning Methodology

Module 5 - Power Systems Interconnection

Highlights

- Imperative need to ensure an **adequate level of reliability**
- Strategic importance of adopting **appropriate system planning criteria**
- Necessity of conducting **sufficient power system stability analyses**
- Advantage of using available **advanced power transmission technologies** to provide least-cost optimal solutions
    - System design
    - Interconnection links

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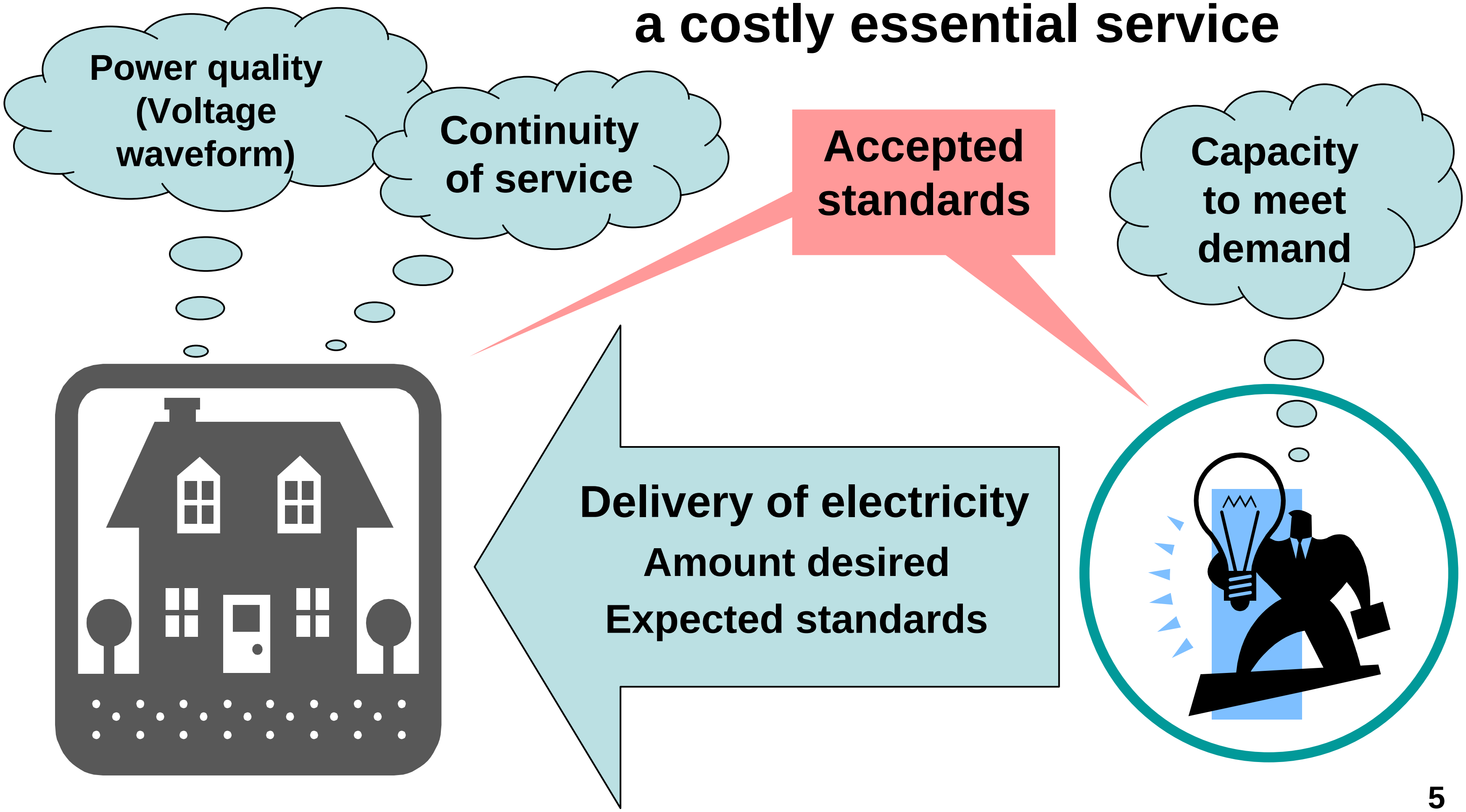
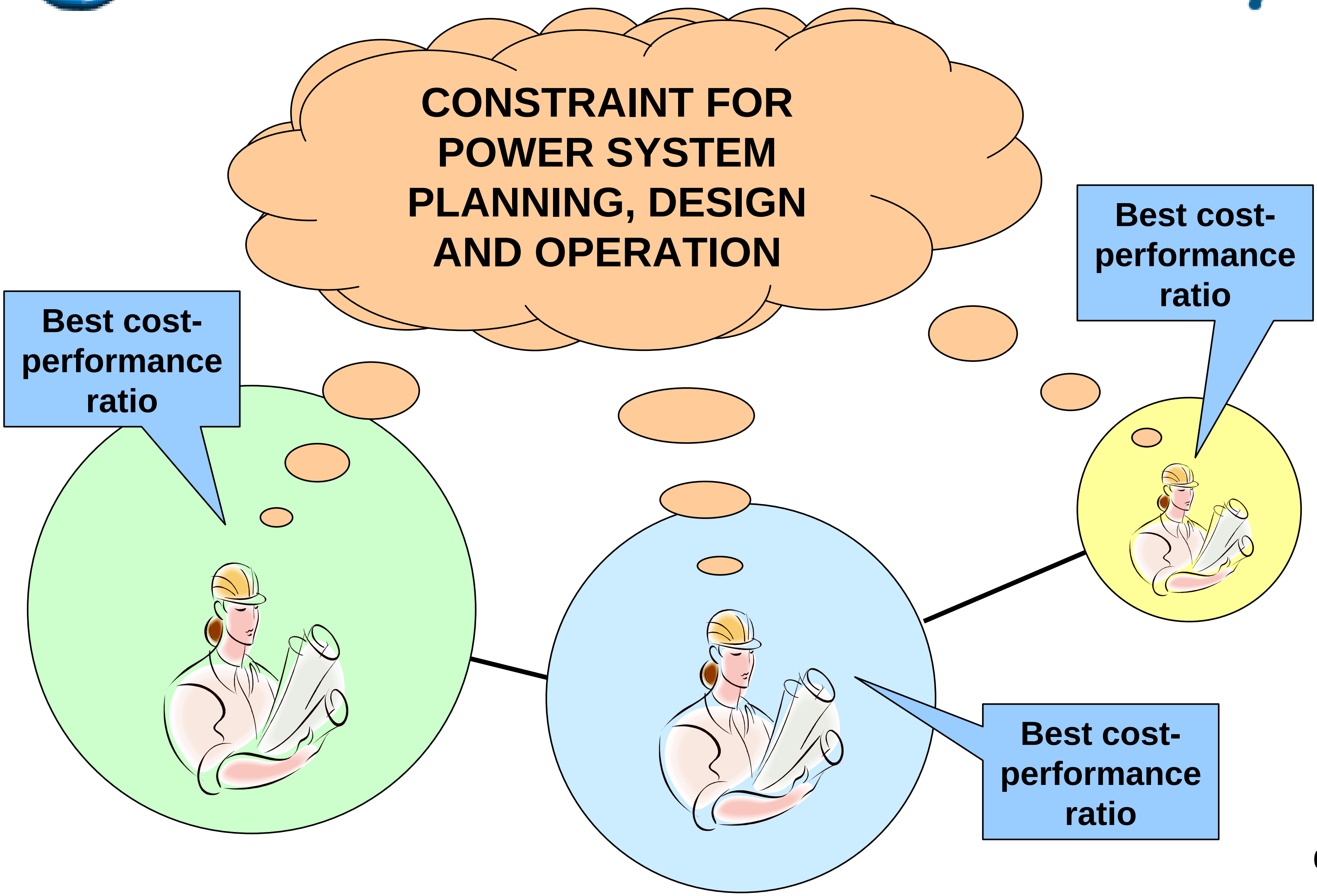
The Importance of Reliability

Determines the level of quality of a costly essential service



Accepted Reliability Standards

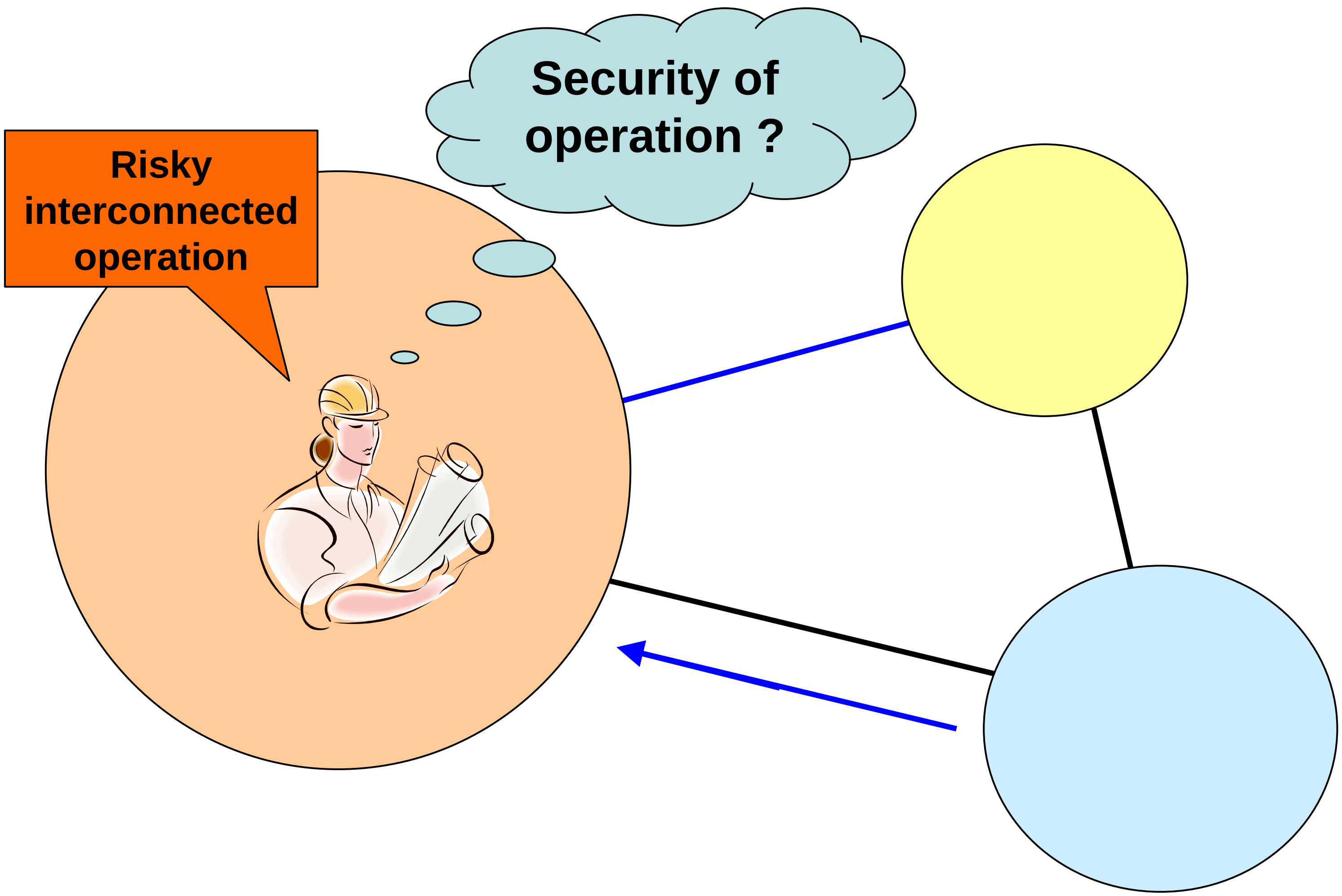


A Strategic Aspect of Reliability

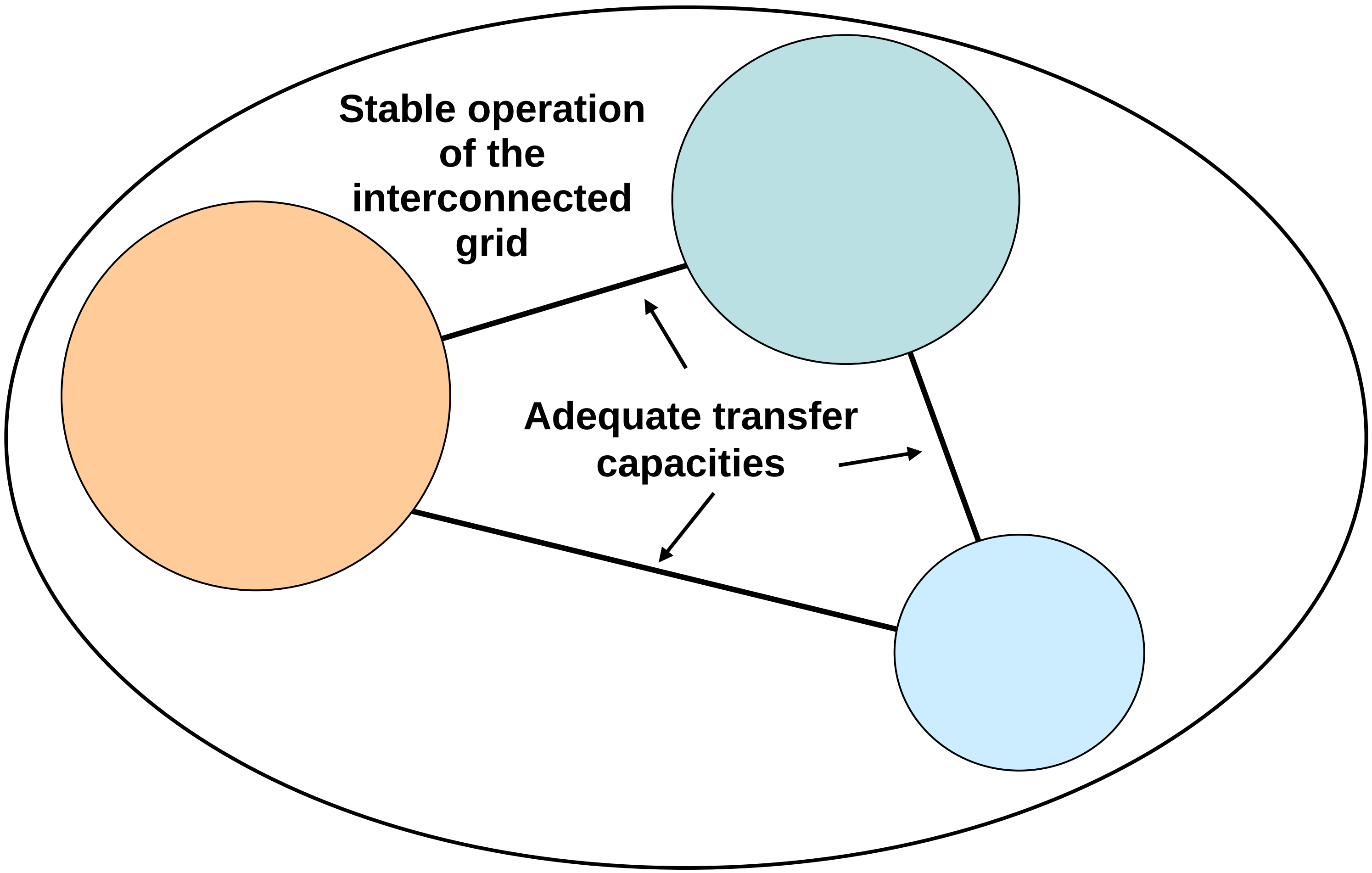
No power system should "suffer" a degradation of reliability due to its new mode of operation within a larger interconnected grid

- Would represent a serious handicap to the success of a RECI undertaking
- Could prevent the partners from reaping the full potential benefits of the pooling of resources

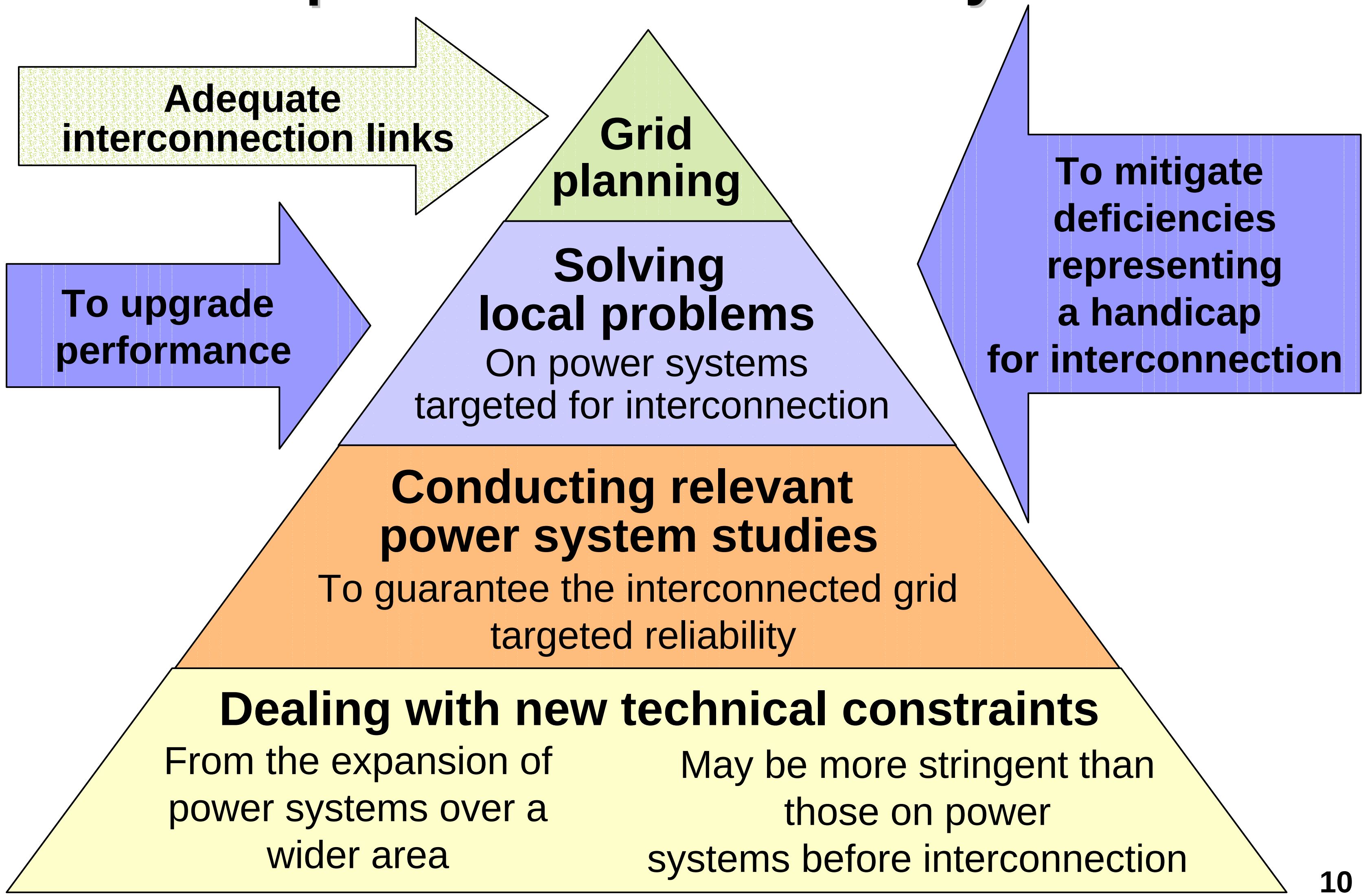
Impact of Reliability Deficiency



Security of Interconnected Operation - Essentially a Transmission System Issue



Requirements to Ensure an Adequate Level of Reliability



Two Essential Reliability Issues

1) To maintain the required supply - demand balance at all times

- **Availability of a sufficient amount of generation**
  - Improved with the pooling of resources inherent in RECI
  - Requires a suitable amount of reserve capacity (determined using more or less sophisticated methods)
- **Sufficient capacity of interconnection links**
  - For the needed transfers of power between interconnected systems

Two Essential Reliability Issues

2) To maintain synchronous operation throughout the interconnected grid in the event of a sudden disturbance

- **A critical reliability issue in a RECI context**
  - **Potentially deteriorated**
    - Far-reaching effects of a larger number of potential faults
    - Possible large power transfers over long distances
- **Efficient fast-acting automatic systems**
  - To maintain continuity of service
  - To prevent catastrophic events
    - Total system collapse
    - Damage to equipment

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The Strategic Importance of Power System Planning Criteria

The means to ensure **implementing the accepted reliability standards** throughout the interconnected grid

Probabilistic
for generation

Deterministic
for transmission

Only feasible approach

Formulated in practical terms for system design

Actually used to validate technical solutions

Applied to the "Bulk Power System"

Considerable impact on the overall system cost

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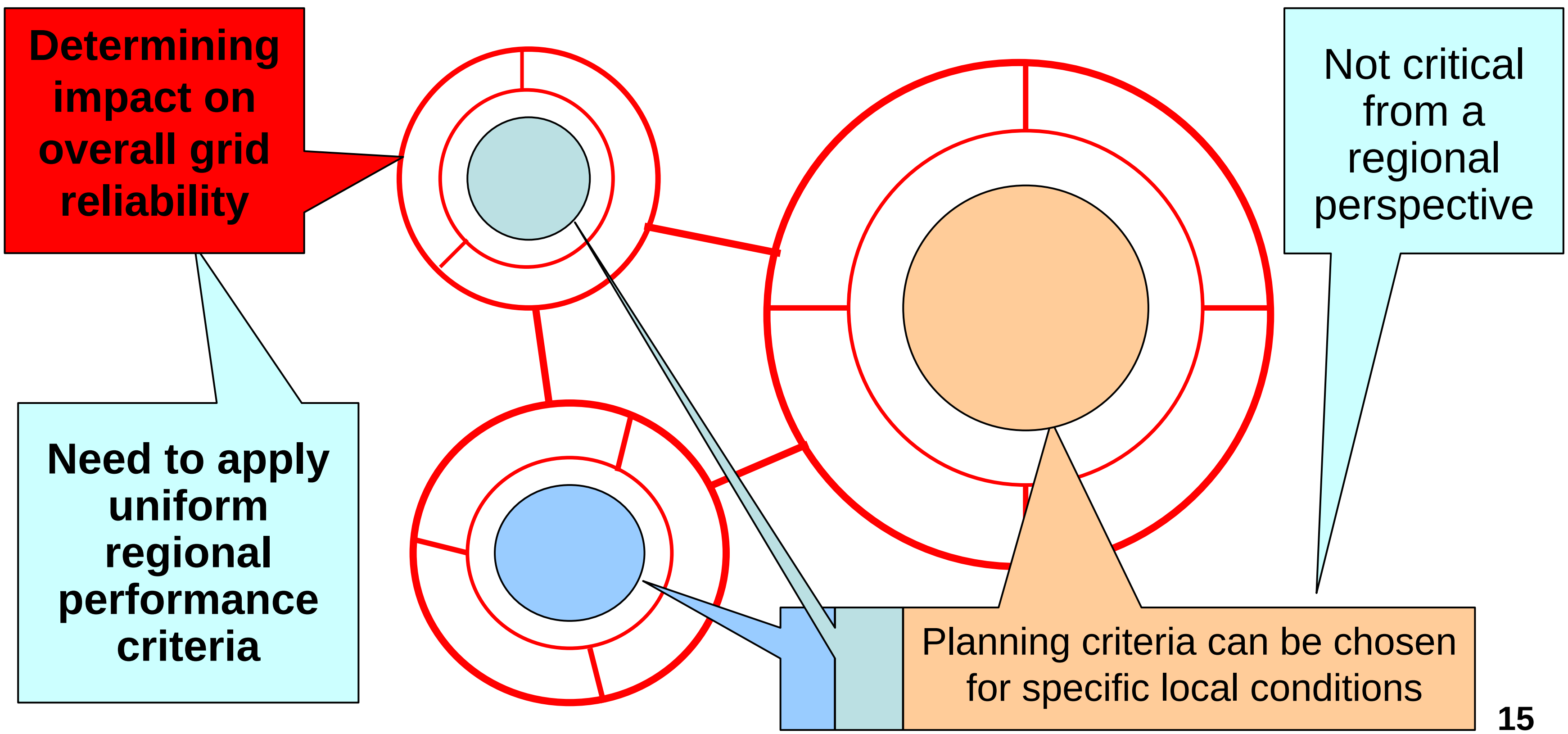
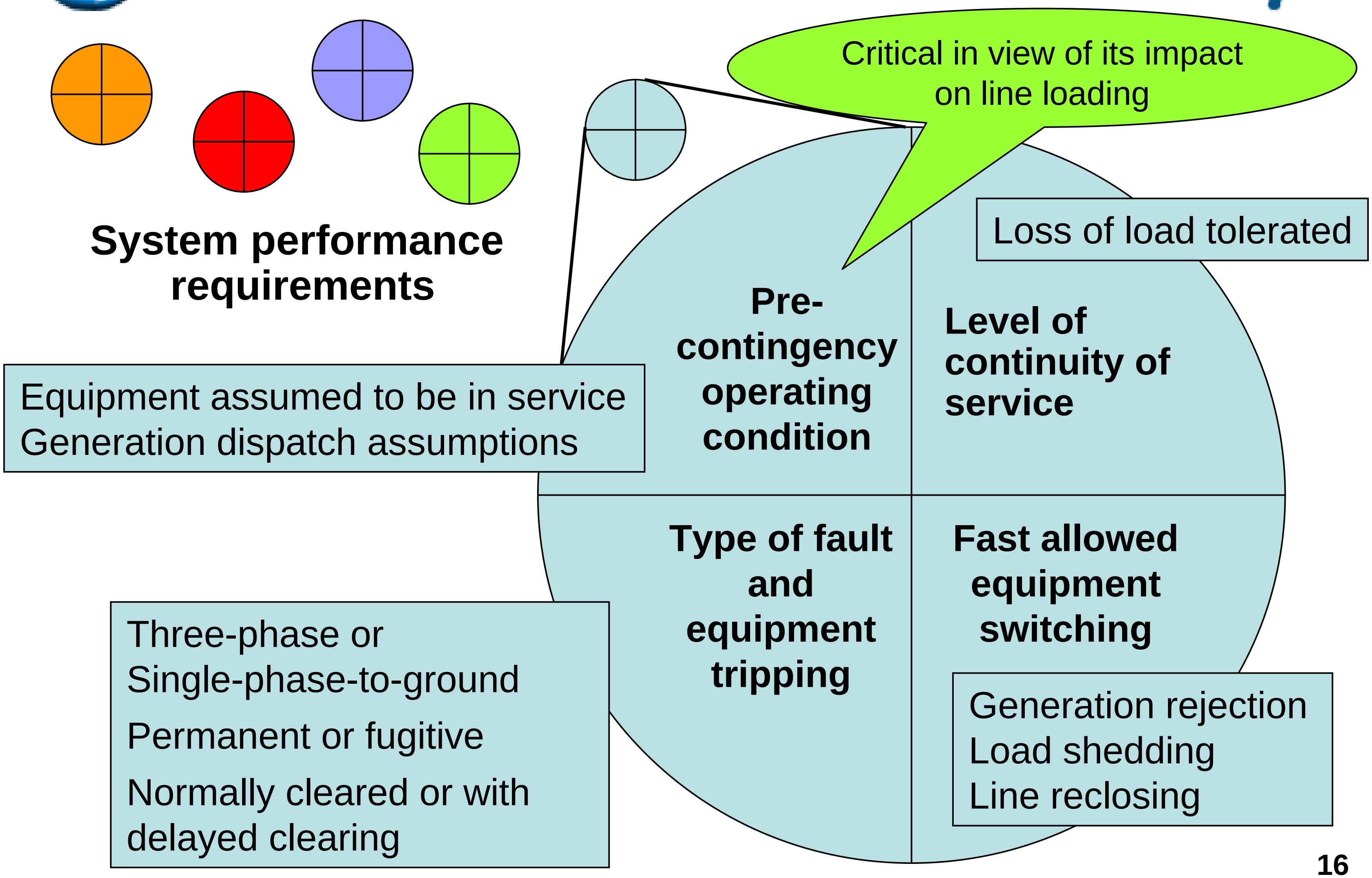
e7 - UNDESA Seminar on Electricity Interconnection

Bulk Power System

The elements of the interconnected grid where faults can have a significant impact outside the immediate adjoining area



Transmission System Criteria



Basic Performance Requirement

The N-1 criterion for a basic level of reliability

Full continuity of service without loss of load

- **Following a fault on a single element**
  - ➢ Normally cleared permanent three-phase fault on a transmission circuit
  - ➢ The loss of the largest generating unit
- **Assuming all equipment in service prior to the fault**

Often extended to a N-2 situation

- ➢ To include the loss of a double-circuit line
- ➢ To assume an element out of service prior to the fault

Additional Performance Requirements

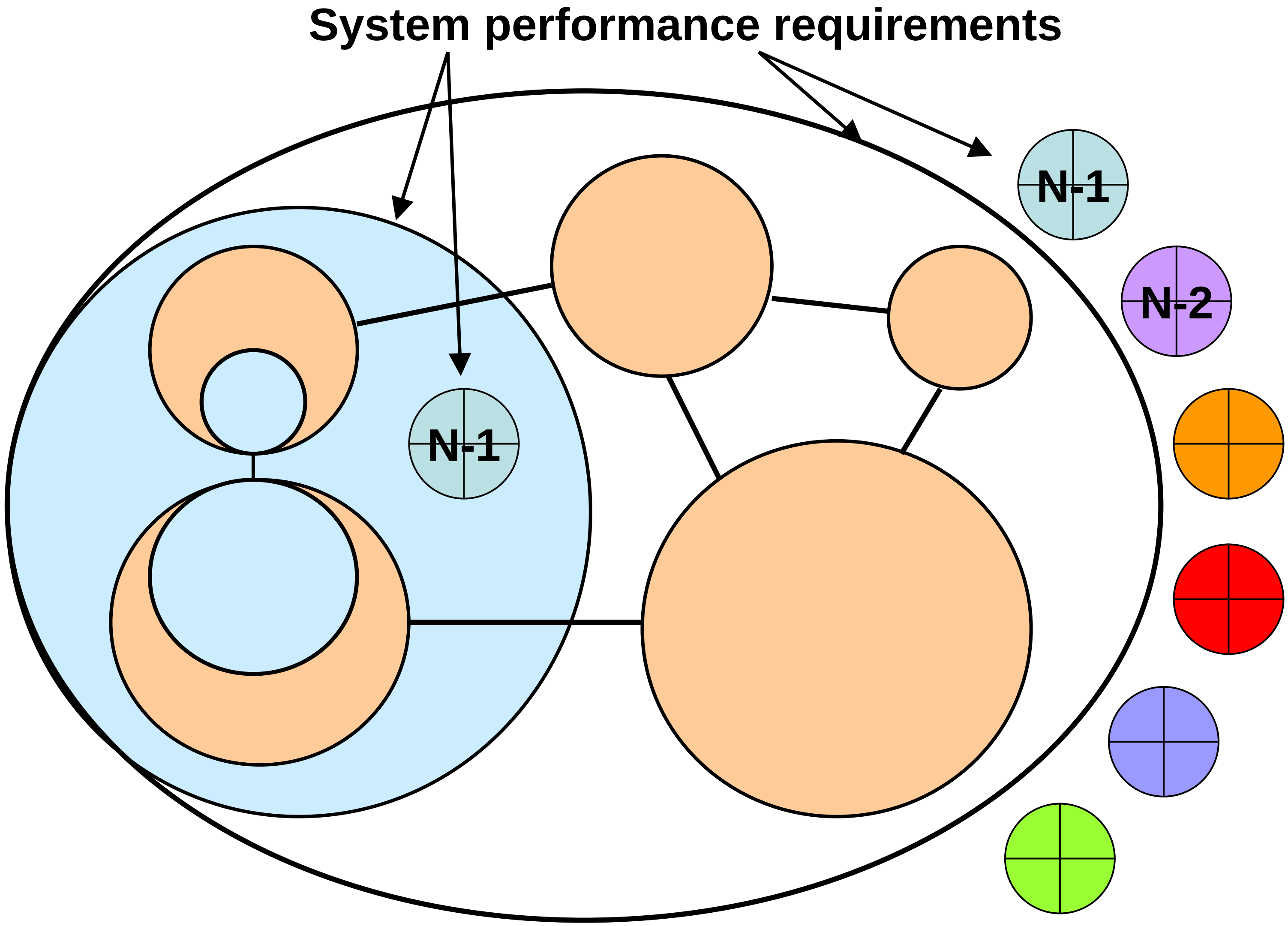
A much more comprehensive set of requirements may become necessary

As the interconnected grid grows larger and more complex

- Larger number of generation and transmission elements
  - Increased number of possible specific contingencies
- More risky operating conditions

May result from the actual operating experience

Evolution of the Planning Criteria



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Selecting a Transmission Technology

System planning criteria → AC / DC → LEAST-COST ALTERNATIVES

A case-by-case decision
(especially for interconnection links)

Comparative advantages (AC vs DC) → **Power system studies (may be extensive and complex)** → **OPTIMAL SOLUTION**

in regard to

Transmission distances
Amount of power to transmit
Relative strengths of the systems

Safe operation of the grid

Sound performance of the interconnection links

Alternating - Current Technology

More flexible and cost-effective as well as less complex

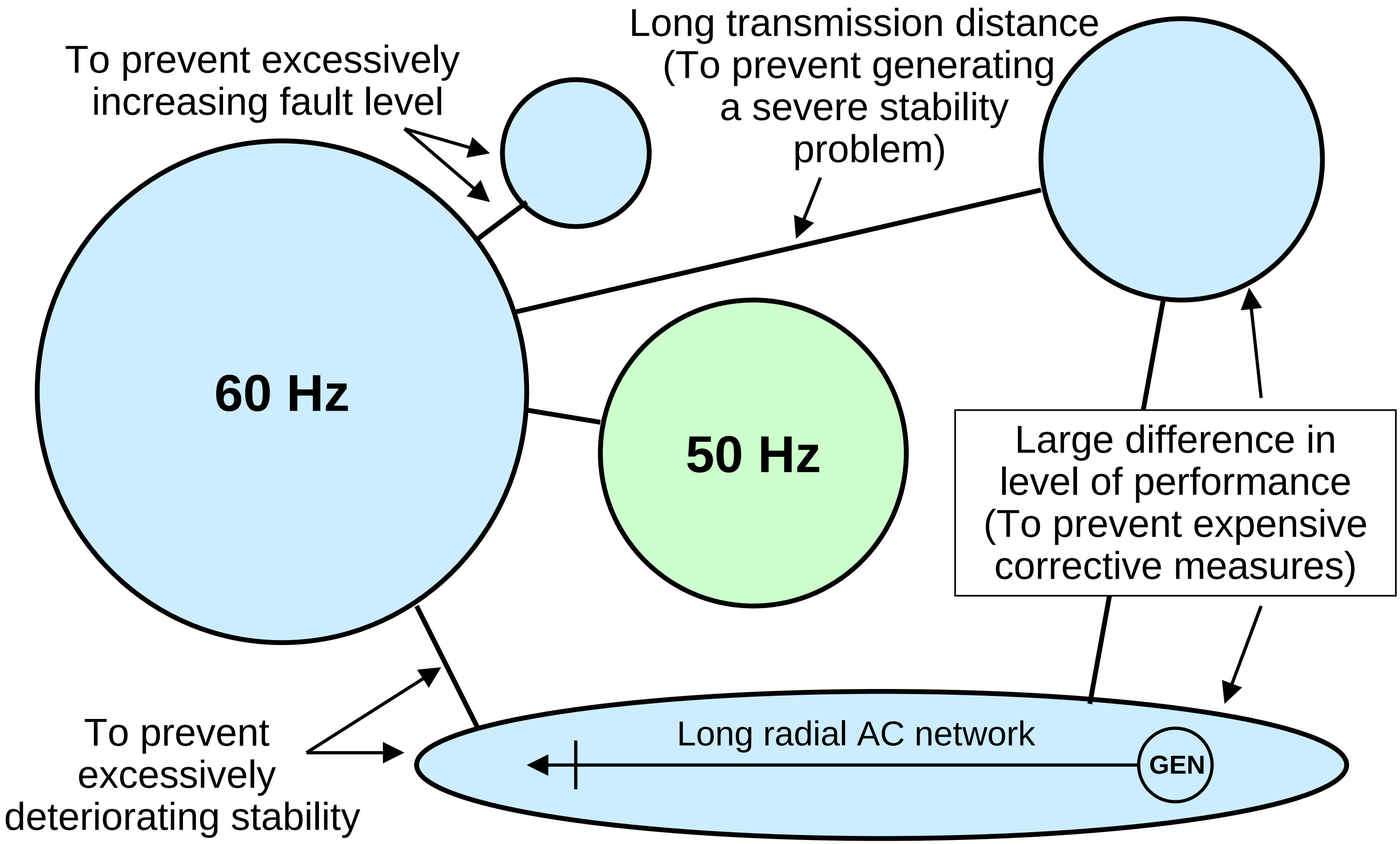
- Generally provides the most appropriate solution for power transmission and systems interconnection purposes
- **Some advantages:**
  - Widely used (the “standard” technology)
  - Not likely to represent the introduction of a new technology on the systems to be interconnected
  - **Can be optimized with the use of cost-effective specialized equipment**

Direct - Current Technology

Immune to frequency variations between interconnected AC systems

- Normally used when a non-synchronous link is either required or **justified as an optimal solution**
- **Some advantages:**
  - Has benefited from significant advancement in semiconductor technology **(has become more competitive in the case of weak AC systems)**
  - Does not increase the fault current
  - Well suited for submarine transmission

Situations Favorable to DC



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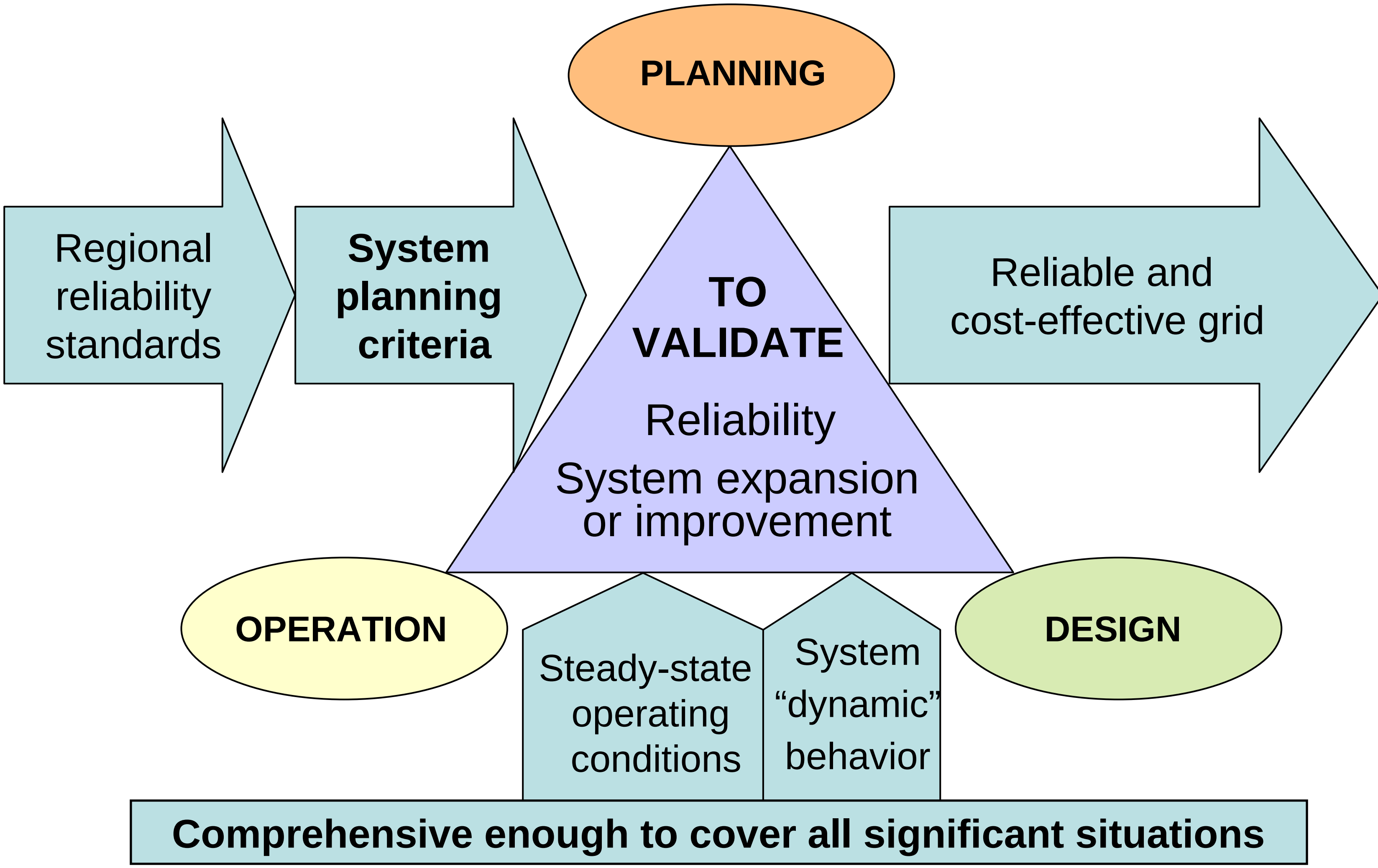
Power System Studies



Types of System Studies

Steady-state operating conditions (Supply-demand balance)

- LOLP evaluation for generation planning

1) Power flow calculations
2) Fault level calculations

Power system “dynamic” behavior

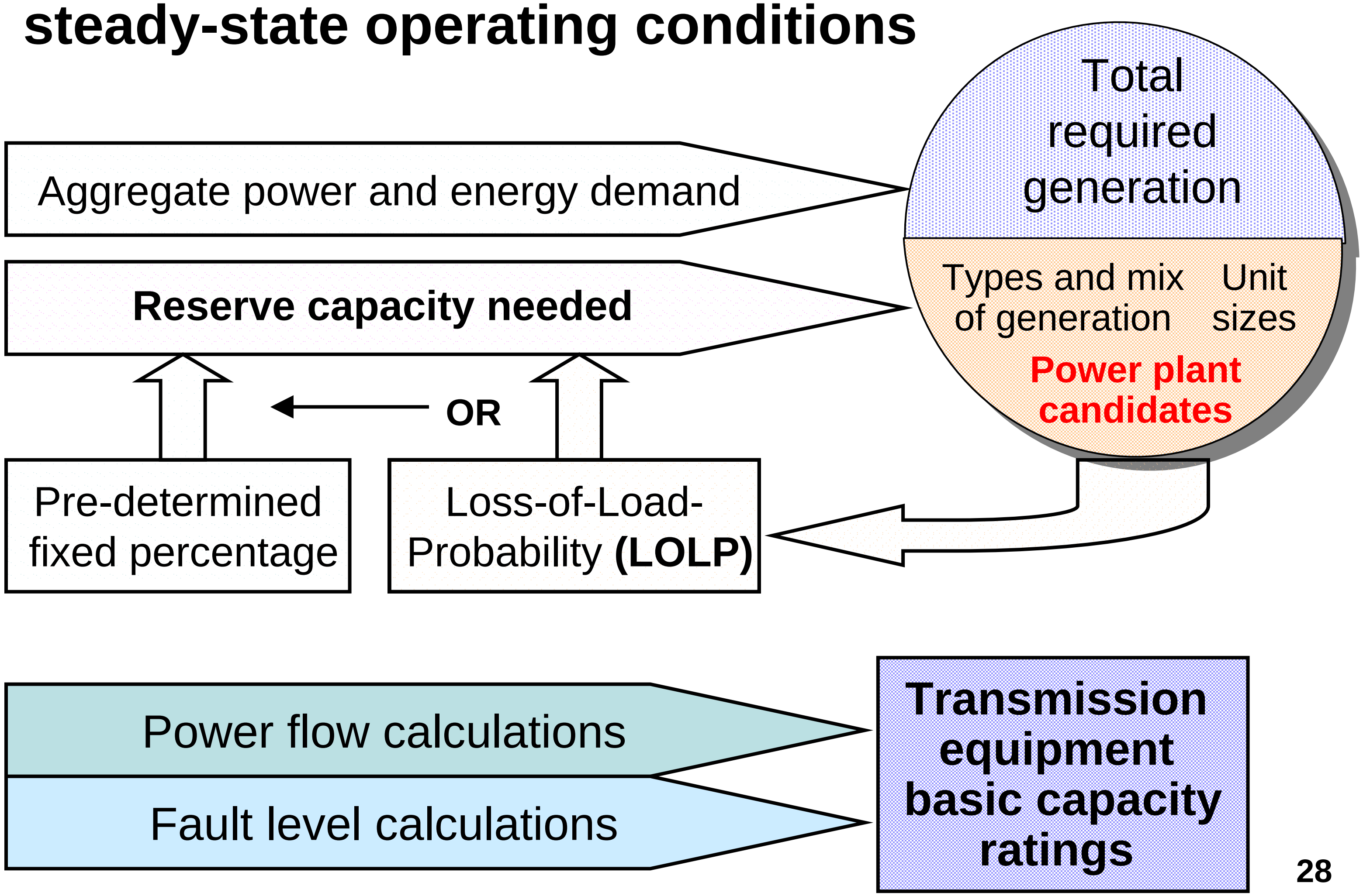
3) **Power system stability studies**

- Fast transients (EMTP) and simulator studies for transmission equipment design

Basic computer software package

Supply-Demand Balance

The aspect of reliability dealing with steady-state operating conditions



1 - Power Flow Calculations

Power transfers required throughout the grid for an optimal generation dispatch at all times

- To check on equipment overload
- To check on inappropriate voltage
- To plan reactive equipment installation

➢ **Especially important when dealing with:**

- **Multiple-point system interconnections**
  - Different paths for actual power flows
- **Long and heavily loaded lines**
  - Result in voltage support problems

➢ **The "corner stone" of transmission system studies**

2 - Fault Level Calculations

Closely associated to power flow calculations

- May use the same mathematical algorithms

Short-duration capacity of the equipment required to cope with short circuit currents

- **To check on insufficient circuit breaker capacity**
- To check on insufficient short-duration ratings of substation equipment
- To check on communication disturbances

Especially important for a small power system being synchronously interconnected with a much larger one

- May be subjected to a drastic increase of short circuit currents magnitude

3 - Power System Stability Studies

The aspect of reliability dealing with transient operating conditions and power systems "dynamic" behavior

Stability: The ability of the system to withstand sudden disturbances and still maintain continuous stable operation

To check on the synchronous operation of generators following typical contingencies:

- Short circuit on a generation or transmission equipment
- Sudden loss of a generator

Focused on the identification of needed:

- System reinforcements
- Protective control measures

The Importance of Stability

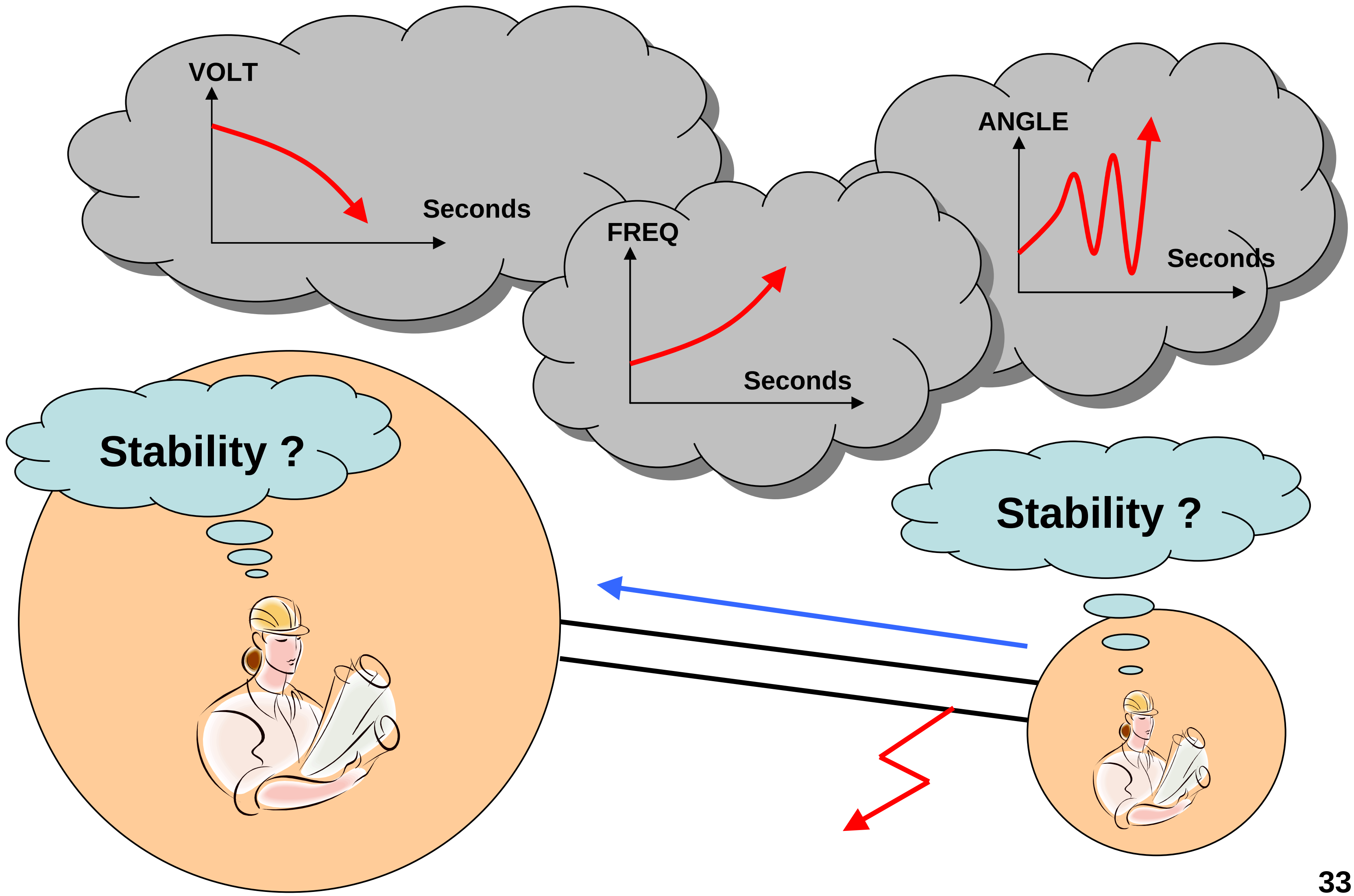
Likely to become an important aspect of grid design when power systems are interconnected

- Much expanded transmission grid

May represent a new type of technical issue that **should not be overlooked**

- Stability studies may not have been needed for the previously isolated power systems
  - No established tradition of performing stability studies

Awareness of System Stability



New Technical Challenges

Emergence of inter-area modes of oscillation

- Risk of loosing synchronous operation due to insufficient damping of post-fault power oscillations

Possibility of transmitting large amounts of power over long distances

- To take full advantage of the most economical generation
  - Risk of load voltage collapse due to a lack of sufficient reactive power to prevent long term voltage instability

The Tools for Stability Analyses

Basically:

Transient stability computer software programs

- **To simulate the power system dynamic behavior**
  - With a sufficient degree of precision
  - Considering all possible types of disturbances

Occasionally:

Specialized **small signal modal analysis programs**

- For a detailed analysis of the power system modes of oscillation
  - Determining effect on system behavior
- **Can help to identify optimal solutions**

The Main Stability Problems

Excessive frequency deviations after a disturbance (or insufficiently damped power oscillations)

- Loss of synchronism and the tripping of generators
  - Over-frequency following a severe short-circuit
  - Under-frequency following the sudden loss of a generator

Voltage instability

- Slow and gradual voltage collapse throughout the system
  - Long term phenomenon
  - Involving a lack of sufficient sources of reactive power

Complex cascading effects of equipment tripping

- Can lead to a system-wide blackout

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Possible Improvement Needs

Basic system improvement techniques

Advanced transmission technologies

Increased power transfers

Increase the current carrying capacity of transmission equipment

More risky operating conditions

Guard against system instability

Solve local problems as a prerequisite for interconnection

Optimize the overall interconnected system performance

Basic System Improvement Techniques

- High-speed fault-clearing equipment (relays and circuit breakers)
  - Very cost-effective to improve transient stability
- **Fast-acting static excitation systems with Power System Stabilizers** on generators
  - Very cost-effective to improve transient stability and the damping of post-fault oscillations
- Adoption of high-speed governors on thermal generation units

Basic System Improvement Techniques

- Addition of transmission lines and intermediate switching stations along transmission corridors
  - Representing expensive solutions
  - May not be avoidable when a large increase of power transfer capacity is needed
- Reduction of the impedance of series equipment
  - Generators
  - Transformers

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1) Advanced Transmission Technologies

1) Planning Methodology

Advanced Transmission Technologies

Can be applied to **further optimize** the design of an interconnected power system

- Beyond the potential of basic system improvement techniques
- **At lower cost than adding transmission lines and substations**

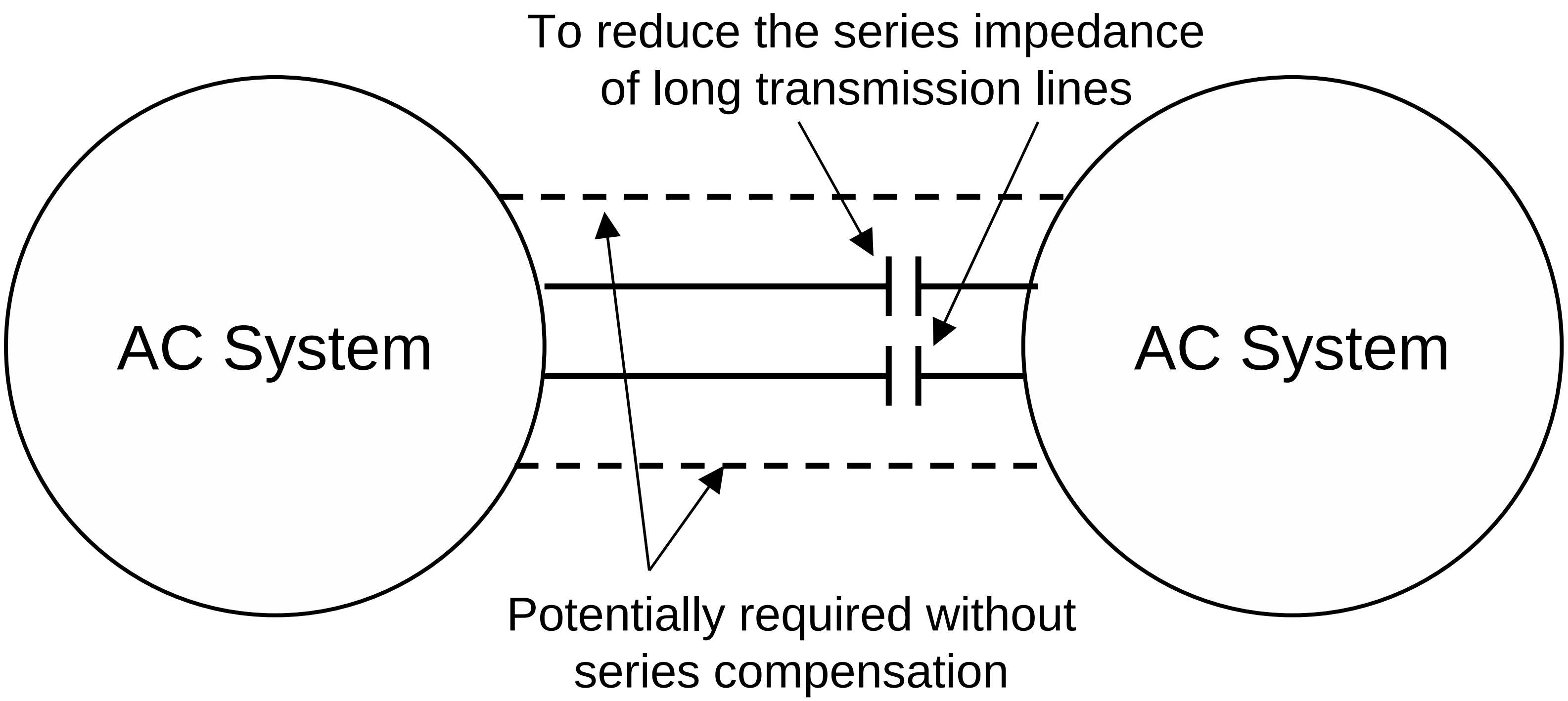
Can provide least-cost solutions and efficient technical facilities

- To enhance the performance of local power systems
- To implement interconnection links.

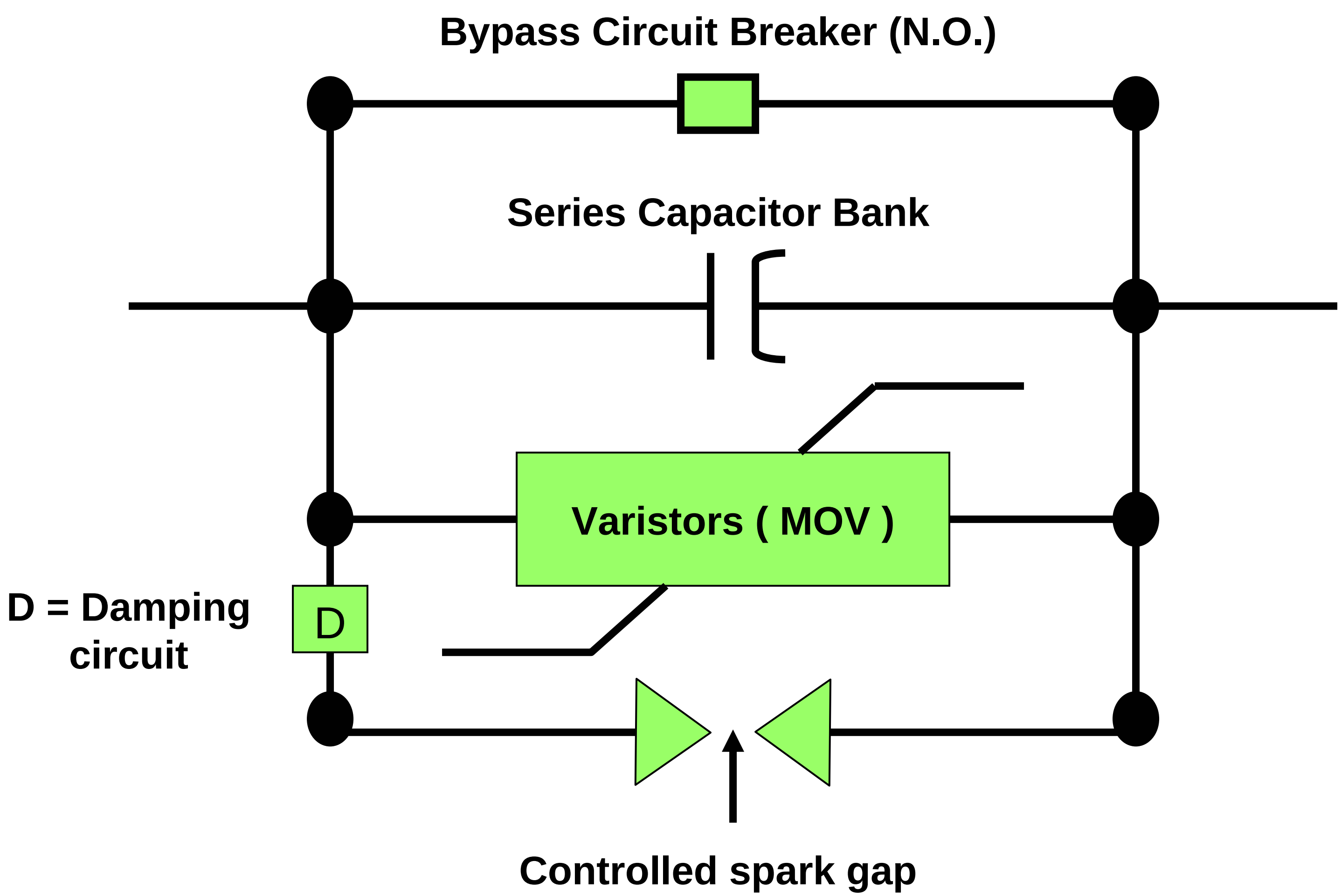
Series Compensation

A classical and widely used technique to optimize AC power system design

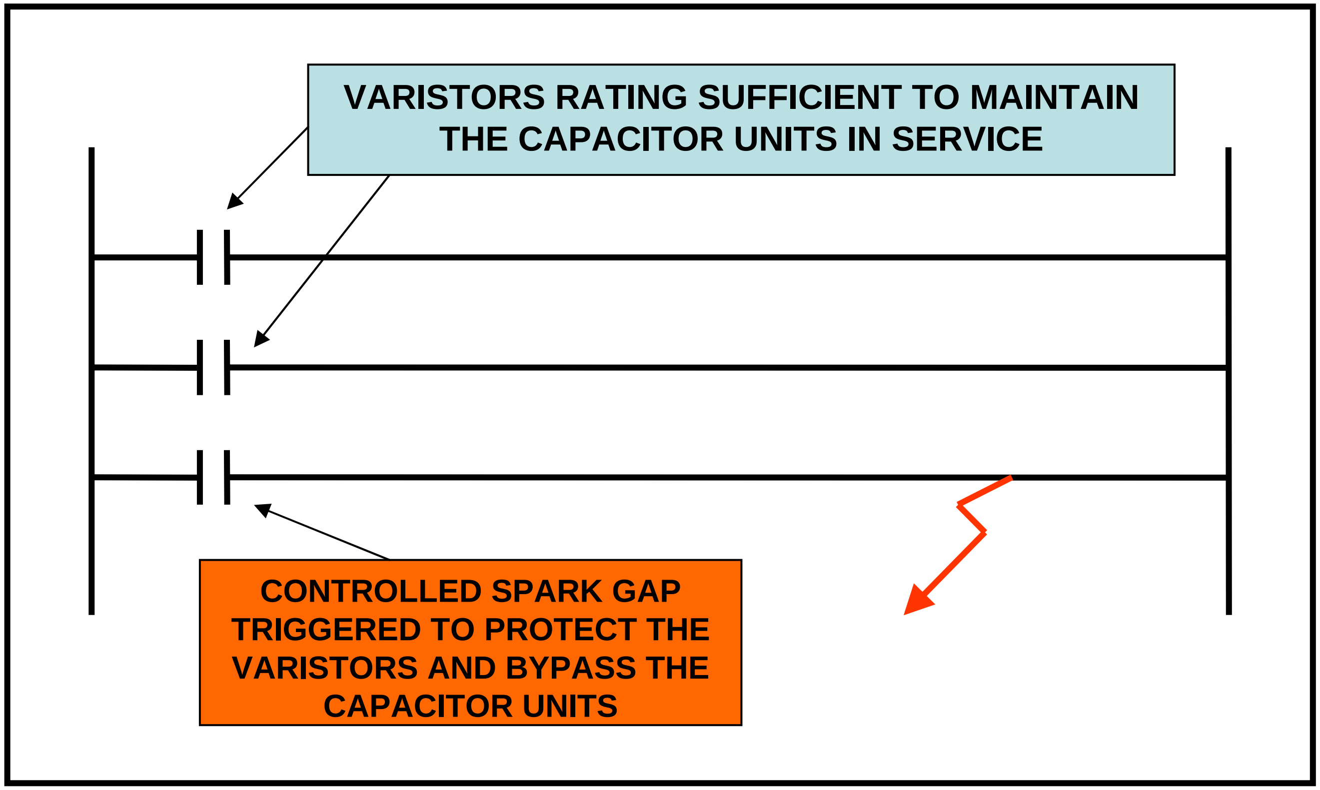
Normally used to solve a severe stability problem



Advanced Protection Scheme



Enhanced Reliability with MOV



Flexible AC Transmission Systems (FACTS)

A sophisticated and flexible way of improving stability and power transfer capability using **advanced power electronics and control techniques**

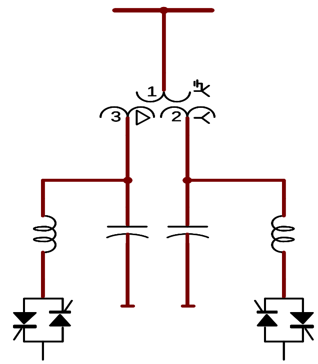
Static Var Compensator (SVC)

- The best known and most widely used
- Very efficient on Extra High Voltage transmission systems
  - Highly capacitive characteristics of transmission lines
    - A significant negative impact on post-fault stability

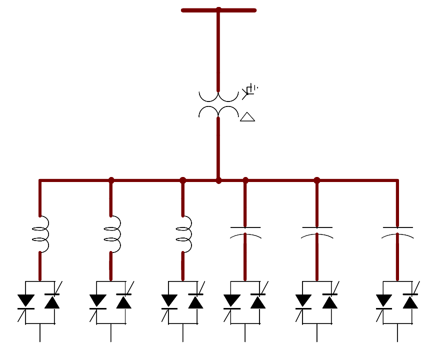
STATCOM

- Faster response time than with the SVC
  - Uses high-power controlled turn-off devices
    - Insulated Gate Bipolar Transistor (IGBT)
    - The older less effective Gate Turn-Off (GTO).

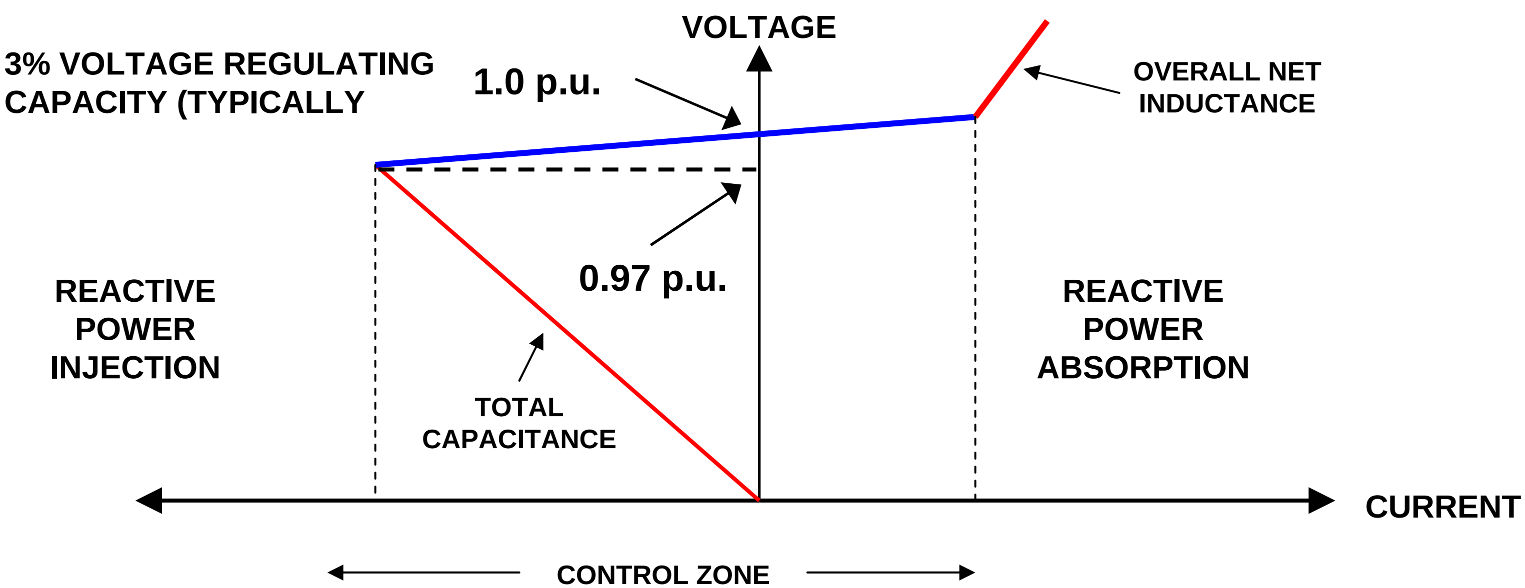
Static Var Compensator



TCR type (12 pulses)



TSC-TCR type (6 pulses)



Complementary Techniques

Variable Series Compensation

- Can be used in conjunction with fixed series compensation to provide additional control features
    - Damping of power system oscillations
    - Solving a sub-synchronous resonance problem

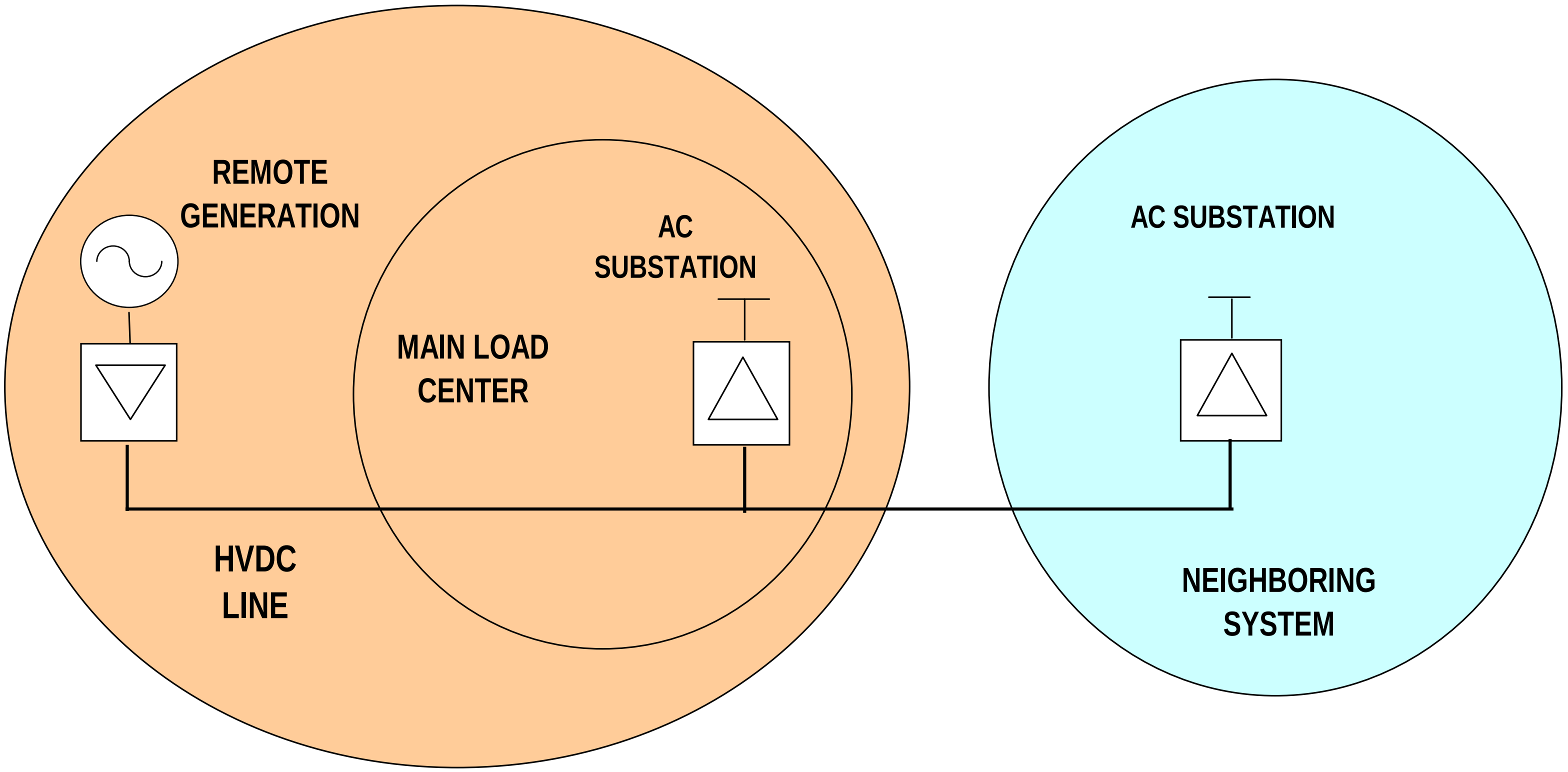
Braking resistors

- To improve transient stability by reducing the maximum frequency rise after a short-circuit
    - Increasing the “first-swing-stability” of generators
- A cost-effective solution, but requires sophisticated control mechanisms
    - Can benefit from the use of IGBTs or GTOs

Multi-Terminal HVDC Systems (MTDC)

- Can be used to overcome a certain lack of flexibility when using DC
  - Providing the capacity to feed loads or pick up generation at intermediate points along the DC line
- Can provide an optimal and flexible solution to meet a possible dual-purpose need
  - Increasing power transmission capacity within a power system
  - Providing an interconnection capacity with a neighboring system
- **Require extensive simulator studies to properly design the control systems**
  - **A critical aspect of MTDC operation**

Three - Terminal DC Link

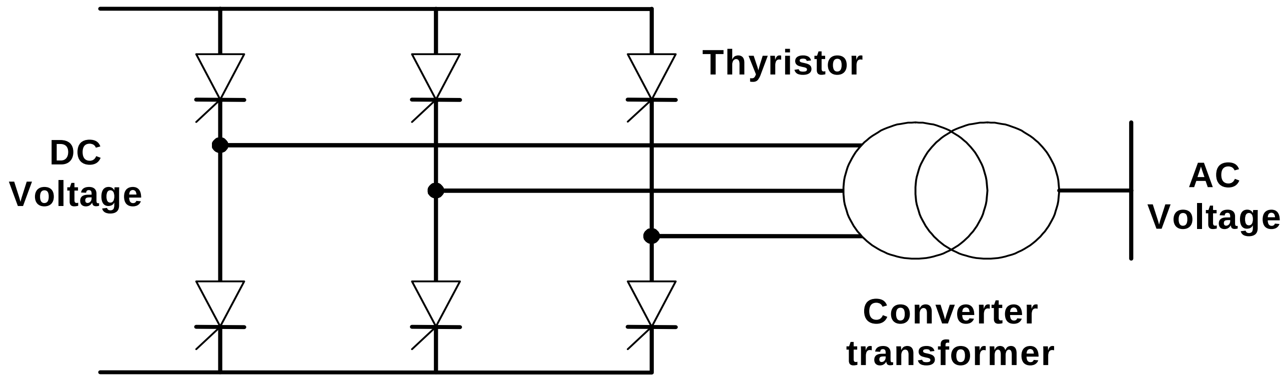


Self-Commutated DC Converters

- Capacity to maintain commutation under conditions of severe voltage drop or waveform distortion
  - Incorporate recent advances in semiconductor technology (high-power controlled turn-off devices)
- **Especially well adapted for the interconnection of weak power systems**
  - Low short-circuit capacity at the DC inverter station

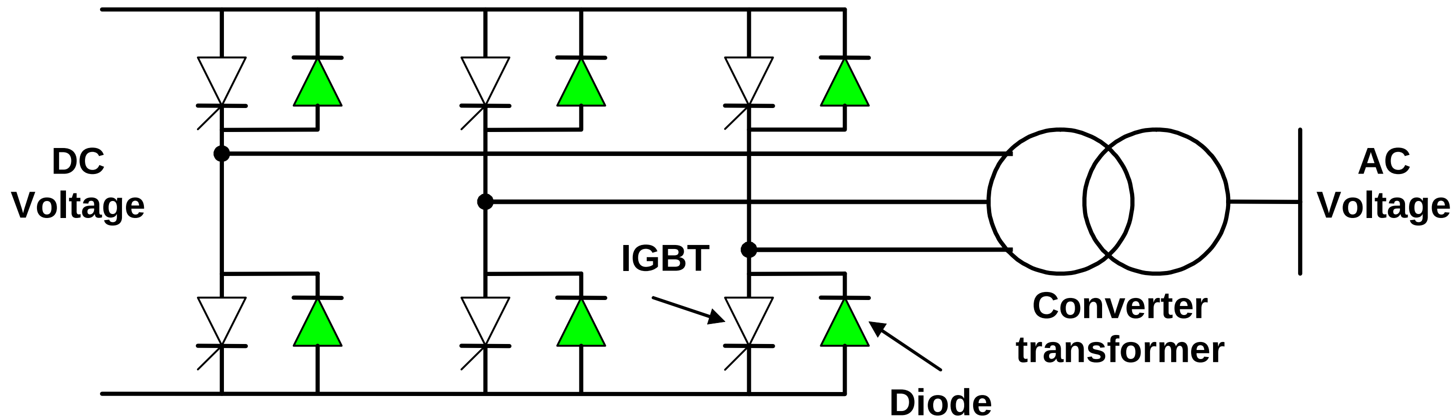
DC Converter Technology

CONVENTIONAL DC CONVERTER



SELF-COMMUTATED DC CONVERTER (VOLTAGE SOURCE)

(INDEPENDENT CONTROL OF ACTIVE AND REACTIVE POWER)



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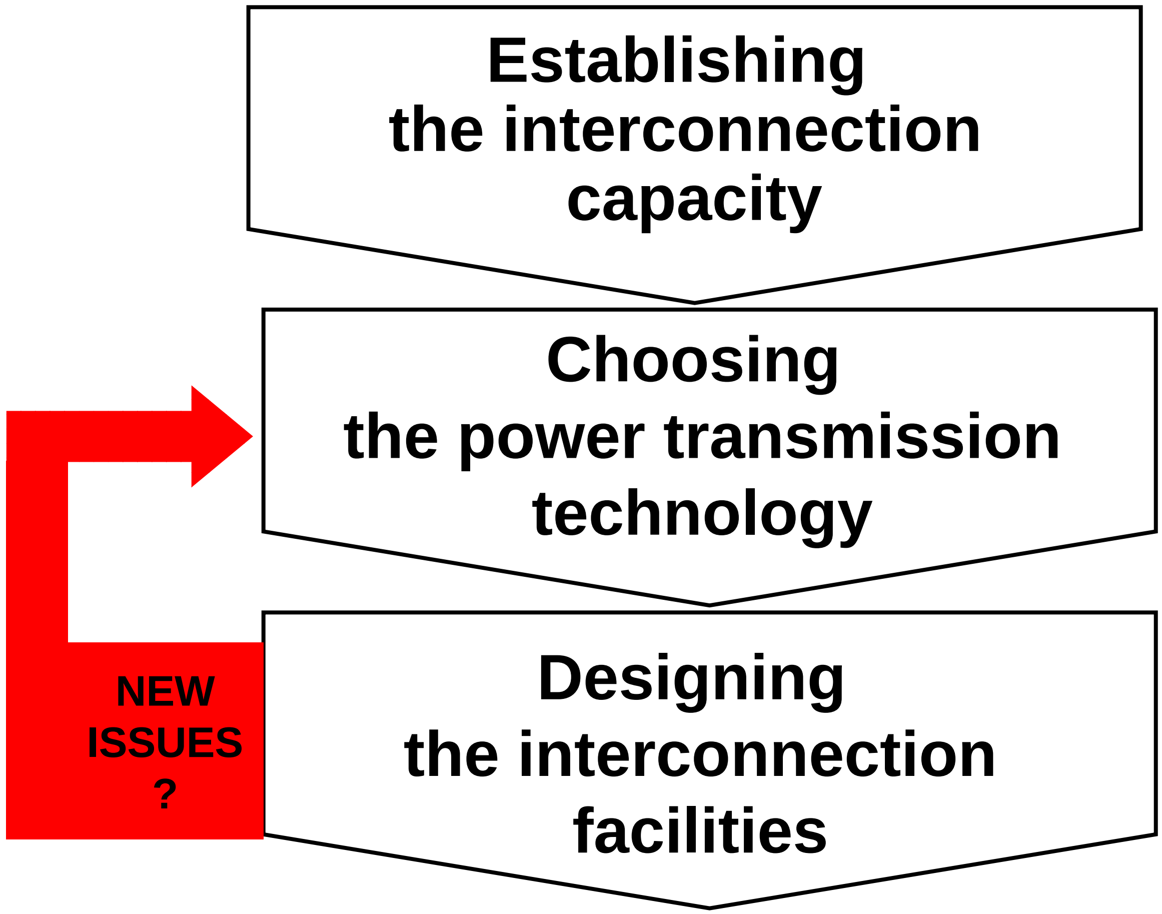
Basic Planning Methodology for Interconnection Links



OPTIMAL SOLUTION AND DESIGN PERFORMANCE REQUIREMENTS

1. Establishing the interconnection capacity

- **Needs a careful evaluation of the forecast power exchange requirements**
  - Coordinated development and operation of power plants to reduce the production cost
  - Reserve sharing
  - Market opportunities for power exchanges

2. Choosing the power transmission technology (and voltage level)

- **Requires a careful assessment of the major technical constraints**
  - Requirements for power system stability
  - Impact on voltage control and fault currents
  - Impact on the existing systems performance
- To obtain the most economical solution while meeting the specified planning criteria

3. Designing the interconnection facilities

- **Requires extensive power system simulation studies to establish all relevant equipment design parameters**
  - Steady-state and dynamic behavior of the interconnected system (power flow, fault level and stability studies)
  - **In some cases, extensive EMTP and simulator studies to evaluate**
    - Voltage and current stresses on the equipment
    - Control system performance specifications

3. Designing the interconnection facilities

- **Other important requirements**
  - Equipment and system protection
  - Power flow control and metering
    - **Not to be overlooked and becoming complex when many entities are involved in power purchase and wheeling activities**
  - Voltage and frequency control
  - Environmental issues
- May lead to the need for power system improvements in addition to the interconnection link facilities