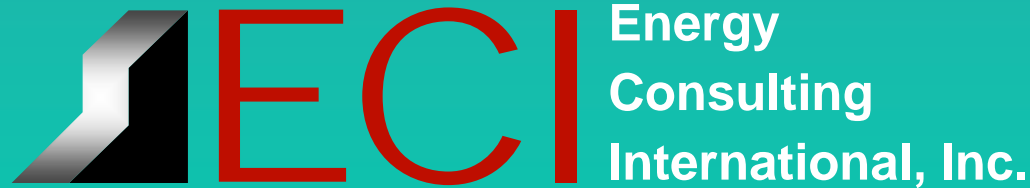


March 16, 2009 Panel Session
Real-Time Stability Assessment in Modern
Power System Control Centers

Overview of Key Stability Concepts Applied for Real- Time Operations

Paper PSE-09PSCE0657 presented by

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Right for Today. Ready for Tomorrow.



Background

- Modern grids sustain MW transfers that may be higher than those for which they were planned
- System operators must meet conflicting requirements
 - allow access to, and maximize the use of, the grid
 - avoid the risk of blackout
 - instability may happen even if thermal limits are not violated
 - when it happens, instability develops almost instantly and leaves no time to react
 - ☞ ***risk of instability must be predicted ahead of time to leave enough time for preventive / corrective actions***



Background (cont'd)

- **Operating conditions change continuously**
 - ☞ **for the prediction to be timely and accurate, the:**
 - **assessment needs to be performed in real-time**
 - **distance to instability needs to be monitored continuously**
 - **stability calculations must use real-time data that**
 - have been validated for completeness, accuracy and consistency
 - have been produced by a reliable and field-proven state estimator
 - **stability calculations need to be completed within the time span of the real-time network analysis sequence**
 - typically five minutes
 - **the results need to be displayed before the next state estimator run**
 - actually much earlier, in order to allow the system dispatcher to examine the results and take action if needed



Background (cont'd)

- **Due to practical and theoretical difficulties, the solution has to be a compromise between:**
 - depth and extent of the stability analysis
 - level and granularity of the modeling details
 - need and ability to seamlessly integrate the stability computations with the SCADA/EMS platform
 - acceptable elapsed times for performing the calculations and presenting the result
- **More than one way to tackle the problem of real-time and online stability assessment**
 - data, computing and operational environment
 - approach to the search for stability limits



What Are Stability Limits?

- Very different from thermal limits -- the concept of
 - "thermal limit" refers to the physical properties of the material used to build the line / transformer, etc.
 - "stability" refers to a solution of a system of equations
 - for each new system state, there may be a new "stability limit"
 - "stability limit" depends upon the
 - methodology deployed to compute it
 - trajectory followed to approach it
 - how many "stability limits"?
 - how to define and quantify the "distance to instability"?
 - can they be violated?
- Approaches:
 - Transient stability
 - Voltage stability
 - Steady-state stability (in the classical sense)



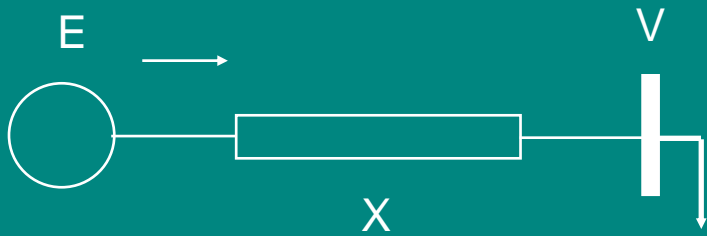
Steady-State Stability Avenue

- Allows quantifying the distance to instability
 - Steady-State Stability Limit (SSSL)
 - total system MW where a small increase of load causes voltages to collapse and units to lose synchronism
 - unsafe (by definition)
 - the system should never be allowed to get close to the SSSL
 - the farther away from the SSSL the better
 - not fixed -- for each system state there is a different SSSL
 - stability reserve -- quantifies the distance to instability
 - must be recalculated after each state estimate and load-flow -- *for current operating conditions and critical contingencies (N-1, N-2, ...)*
- What causes instability?
 - transmission congestion
 - topology changes
 - impact of lower system voltages



Steady-State Stability Avenue (cont'd)

Stability Reserve Concept



conceptual model -- the solution algorithm represents ALL the machines

the power flows from generators to loads

E = generators' e.m.f.

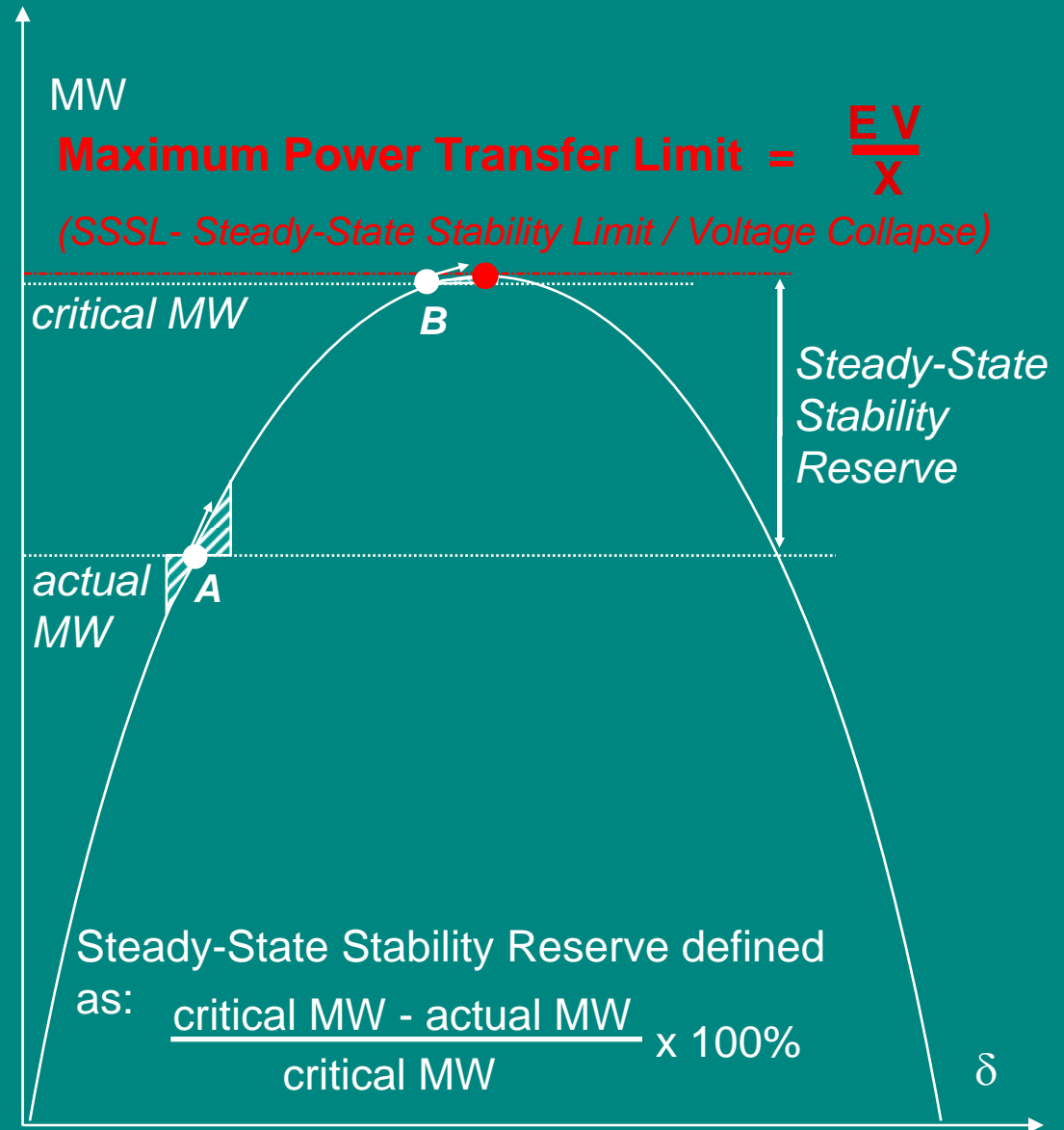
V = bus voltages at load buses

X = transmission system reactance
(includes the generators)

Steady-state stability analysis by using a voltage stability criterion:

Point A -- a small load change does not cause instability

Point B -- a small load change causes voltage collapse and / or units out of synchronism

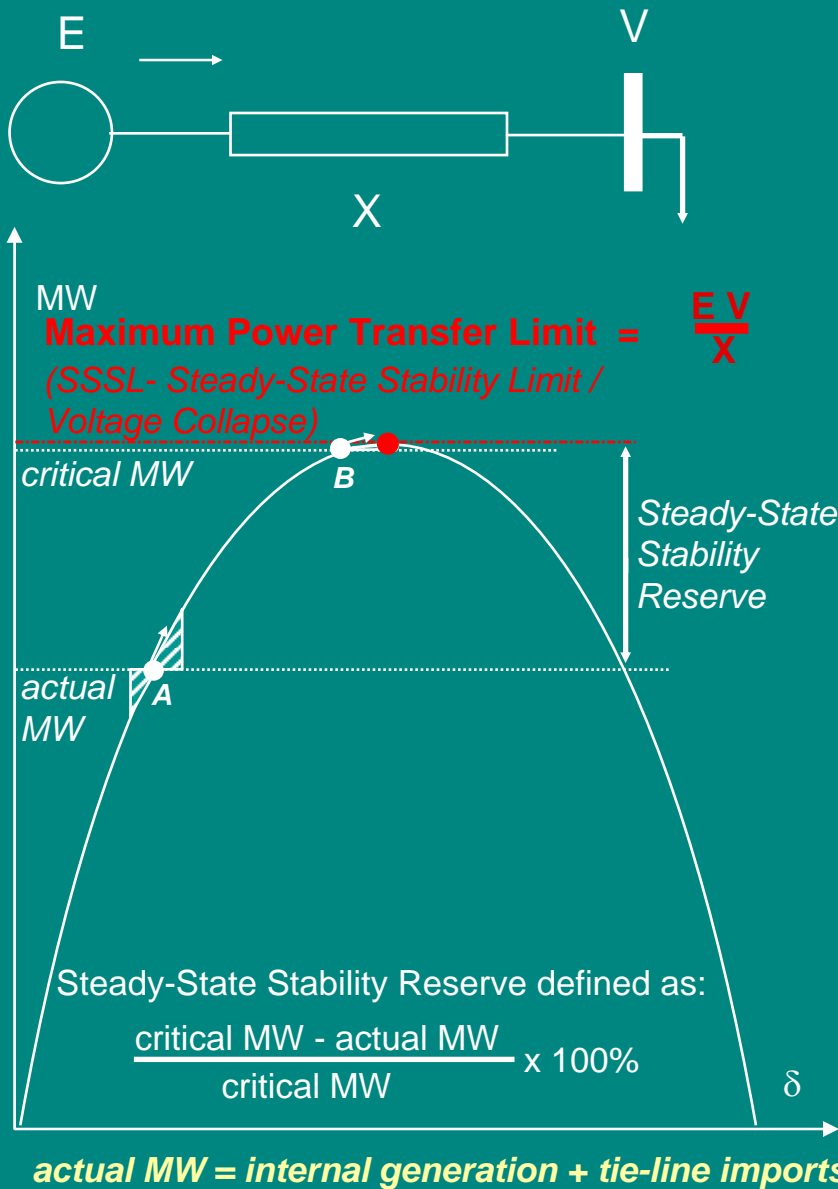


Total MW system grid utilization = internal generation + tie-line imports

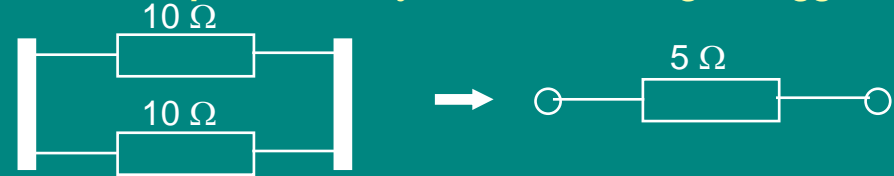


Steady-State Stability Avenue (cont'd)

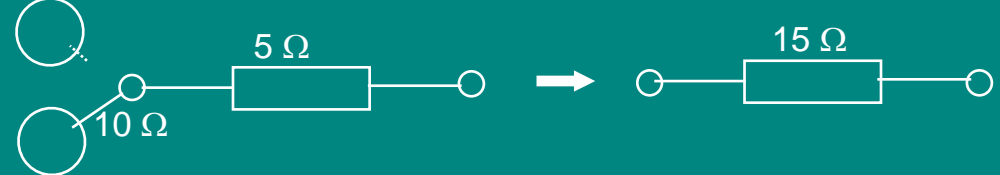
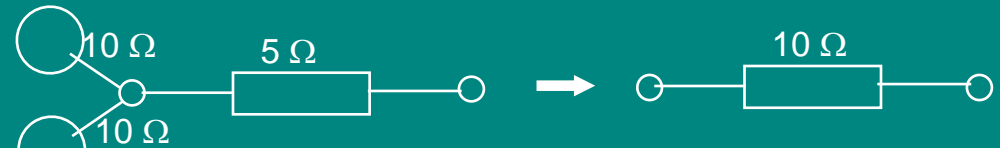
Impact of Topology Changes



when lines trip, the total system reactance gets bigger



when generators trip, the total system reactance gets bigger

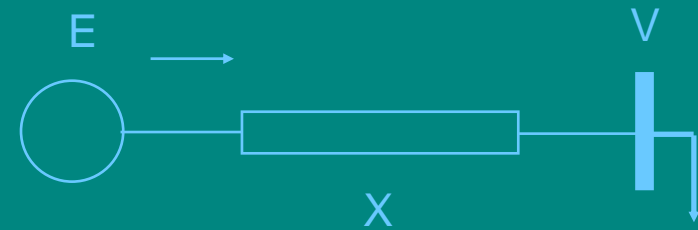
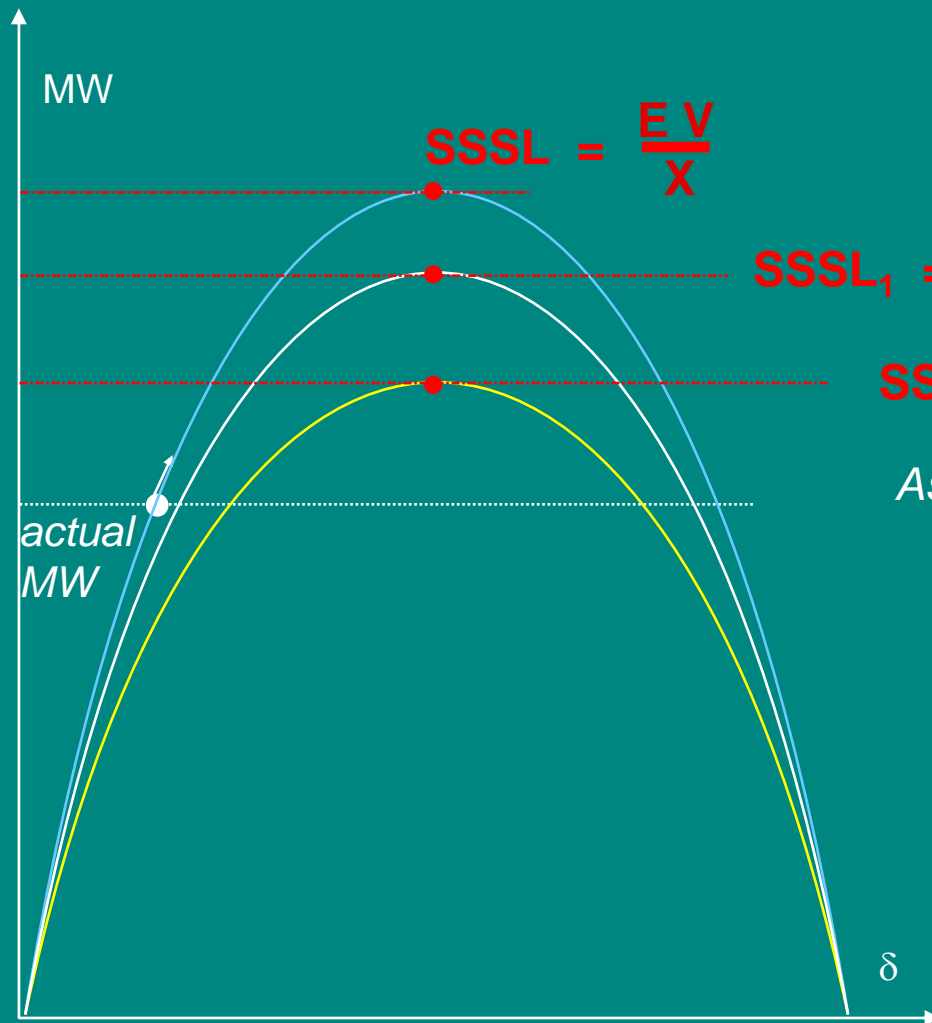


line and generator trips tend to reduce the maximum power transfer limit



Steady-State Stability Avenue (cont'd)

Impact of Lower System Voltages



$$SSSL_2 = \frac{EV_2}{X}$$

Assumptions:

- no topology changes
- same MW loading
- constant generator excitation currents

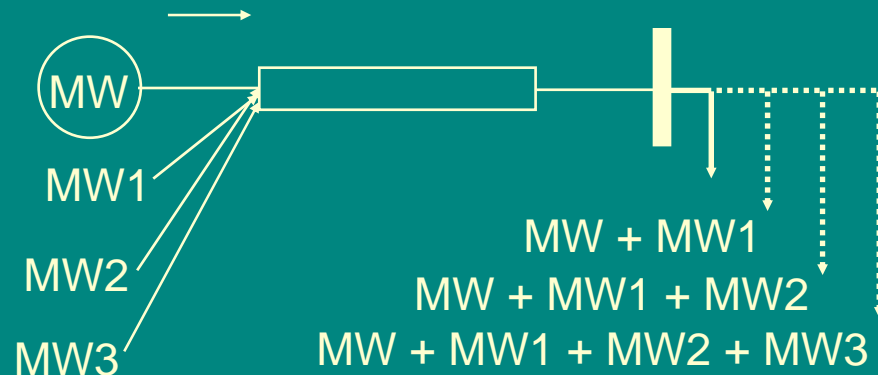
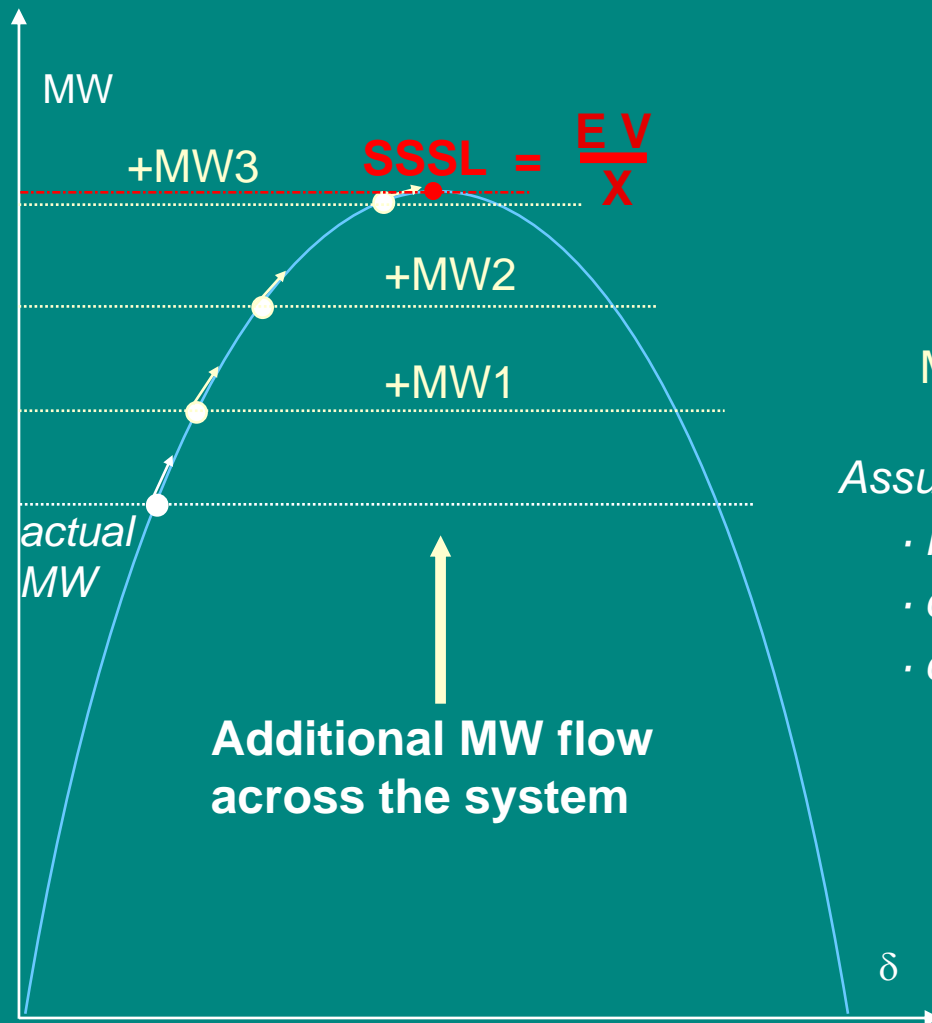
decaying system voltages reduce the maximum power transfer limit

actual MW = internal generation + tie-line imports



Steady-State Stability Avenue (cont'd)

Impact of Wheeling MW Flows -- How "Transmission Congestion" Reduces the Stability Margin



Assumptions:

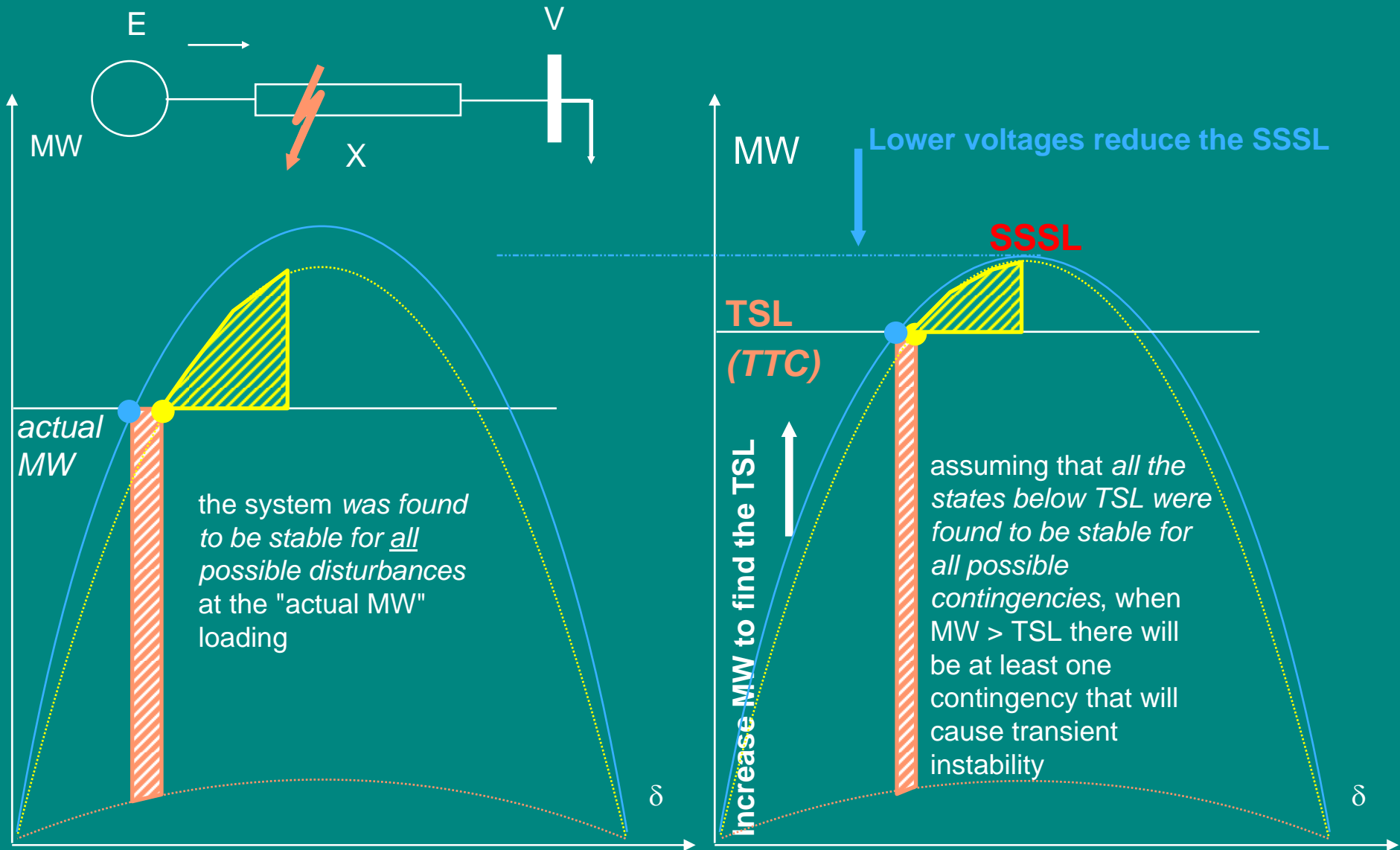
- no topology changes
- constant generator excitation currents
- constant voltages at load buses

external MW flows wheeled across the transmission network, also known as "congestion", push the system closer to its maximum power transfer limit

actual MW = internal generation + tie-line imports



TSL (Transient Stability Limit) Concept



Total MW system grid utilization = internal generation + tie-line imports



Steady-State Stability Avenue (cont'd)

- Need to represent the synchronous machines in voltage stability simulations
 - should examine the singularity of the dynamic Jacobian
 - use steady-state stability analytical techniques
 - be careful with load-flow techniques
 - singularity of the load-flow Jacobian is not a stability criterion!
 - Sauer, W.P., Pai, M.A., "Power System Steady-State Stability and the Load-Flow Jacobian", IEEE Transactions in Power Systems 5 T-PWRS, 4, pp. 1374 - 1381
 - Sauer, W.P., Pai, M.A., "Relationships between Power System Dynamic Equilibrium, Load-Flow, and Operating Point Stability", in "Real Time Stability in Power Systems" (Editor: Savulescu, S.C.), pp. 1-30, Springer Verlag, Norwell, MA, 2006
- Need to monitor the evolution of the stability reserve
 - for normal operating conditions and critical contingencies
 - ☞ ***"any network that meets the steady-state stability conditions can withstand dynamic perturbations and end in a stable operating state"***
(Magnien, M., Rapport Spécial du Groupe 32 Conception et Fonctionnement des Réseaux, Conférence Internationale des Grands Réseaux Electriques a Haute Tension, CIGRE, Session 1964)



Real-Time Stability Requirements

- **System Operation requirements for a real-time stability assessment and monitoring application**
 - must be **fast** so it can perform split-second calculations
 - in real-time, to
 - monitor the distance to instability
 - evaluate critical contingencies for stability violations
 - off-line, to
 - evaluate stability reserves of many alternate operating scenarios
 - select the worst contingencies from large contingency sets
 - ☞ ***dynamic contingency selection***
 - should be **reasonably accurate**
 - theoretically sound simplifying assumptions -- not heuristics
 - should provide answers that are **easy to interpret**
 - distance to instability
 - must display the results **graphically, in simple formats**