



# **Distributed Voltage Control in Electrical Power Systems**

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### Definition of voltage stability

Power system are operated under much more stress than in the past due to these issues:

Competitive markets
Continuous growth of consumption
Transmission expansion doesn't keep pace with generations and loads
Renewable energy sources, micro generations like wind turbines

Voltage stability problems stem from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission and generation system.

### Corrective actions against voltage instability mechanisms

#### • Short-term

driving force: tendency of dynamic loads to restore consumed power in the frame of a second.

reactive support should be able to restore a stable equilibrium point and also fast enough to act before the motors decelerate beyond the post-disturbance unstable equilibrium point.

Most common fast reactive support devices: Fast capacitor switching Static Var Compensators (SVC) Additional local generation like DG (Dynamic Var injection) Discrete events in primary control layer model

Automatic voltage regulators (AVRs): All generators have an AVR maintaining the level of the excitation field  $E_{fd}$  in the rotor windings at the value required to keep the bus (stator) voltage close to the desired set-point.

Saturation is included in the AVR to account for the maximum allowable current in the excitation system, i.e.,  $E_{fd}$  has an upper limit value  $E_{max}$  and a lower limit value  $E_{min}$ .

# OvereXcitation Limiter (OXL):

Protects the field winding from an overheating due to excessive current.



#### System perspective and modeling

Instantaneous response of network:

#### DGs:

• Long-term

Modern DGs (like wind turbines) are interconnected in parallel at PCC ( point of common coupling) to the grid. By generating or consuming reactive power by the inverter, PCC voltage is regulated. The compensator current only has reactive component.



In large disturbance like short circuits, field current may quickly increase up to a maximum value which is typically twice the permanent admissible current and not for more than a few second.

Inverse time characteristic: the smaller overload, the longer time that it can be tolerated

We have to take OXL into account in modeling of AVRs with antiwindup integrators.



#### Secondary control layer

AVR control is local by nature, since it involves only generator buses and voltage at non-generator buses may become unacceptable or the reactive reserves may be unevently distributed over generators after a disturbances,

# $0 = g\left(x, y, z_c, z_d\right)$

y: bus voltages vector x: sate vector z<sub>c</sub>: continuous long-term state vector z<sub>d</sub>: discrete long-term state vector

Short-term dynamics:

The time frame of AVRs and governors, excitation systems, turbines, induction motors, HVDCs components and SVCs. Corresponding dynamics last typically for several seconds

• $x = f(x, y, z_c, z_d)$ 

•Long-term dynamics:

The time frame of LTCs, generator limiters, boilers and their dynamics lasts typically for several minutes following a disturbance.

Components such as generators and loads drive the continuous dynamic behavior. On the other hand, Limiters ( such as OXL), LTC, HVDC and SVC actions lead to discrete events.

After an stable short-term dynamics following a initial disturbance, the system is driven by the long-term dynamics represented by  $z_c$  and  $z_d$  variables.

The most typical long-term voltage instability is loads trying either to recover their pre-disturbance power by LTC actions or to reach their long-term characteristics by self-restoration.

What we aim at is traditionally called secondary control, but we need to model by hybrid system some effects of primary control system.

proposed solution: Distributed control of voltage over intervals of seconds. Control requires coordination of LTCs, SVSs action taking OXL into account. Time scale seconds to 1 minute.

# Voltage control

To control such complex systems, we'll apply hierarchical control:

Several local controllers acting directly on the actuators of the physical system that have been supervised by secondary control layer providing set-points or specifying constraints.

The above objective can be achieved using a variety of control actions, such as reactive compensation switching, generation rescheduling or load reduction that the latter can be reduced indirectly by LTC control. LTC control can be implemented in several ways: So, AVR voltage setpoints of the generators must be adjusted by secondary voltage control.

Supervisory layer should offer controls set-point and reference settings:

The voltage references for the AVRs. The amount of capacitor banks to connect to the grid. Coordination of LTCs

## Some simulation results

The LTCs are slowly acting, discrete devices changing the transformer ratio r by one step at a time if the voltage error remains outside a deadband longer than a specified time delay so that controls the voltage of the distribution, medium voltage.

load restoration performed by LTCs is indirect: when LTC suceeds to restore the distribution side voltage close to its reference value, the load power which in general depends on bus voltage is also restored.

LTC voltage control following a fault at t=1sec in a typical 4 bus system:

Phasors				
		A A		
			21	
		8 77 18		2



Given an initial state and input trajectory, we have to solve the whole set of differential-algebraic, discrete-continuous time equations covering the short and long-term scales in simulation.

So, the behavior of power systems is characterized by complex interactions between continuous dynamics and discrete events, i.e., power systems exhibit hybrid behavior.

**LTC blocking:** can be used for slowing down the system degradation by stopping the load restoration process,

LTC setpoint reduction: is preferable from the viewpoint of customer voltage quality, since although the voltage remains low, it is on the average less sensitive to transmission system transients.

We want to avoid LTC blocking by using coordination when multilevel LTCs are available in the system.

