ELEC0047 - Power system dynamics, control and stability

Long-term voltage stability : generation aspects

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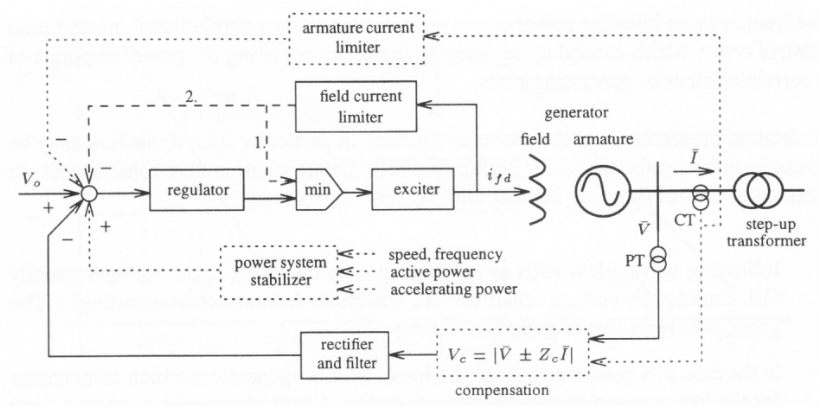
Voltage instability results from the inability of the combined transmission and generation system to provide the power requested by loads

Field and armature current limiters



- field current limit imposed by *OverExcitation Limiter* (OEL)
- armature (or stator) current limit: seldom enforced by a limiter; most often, action by operator in power plant.

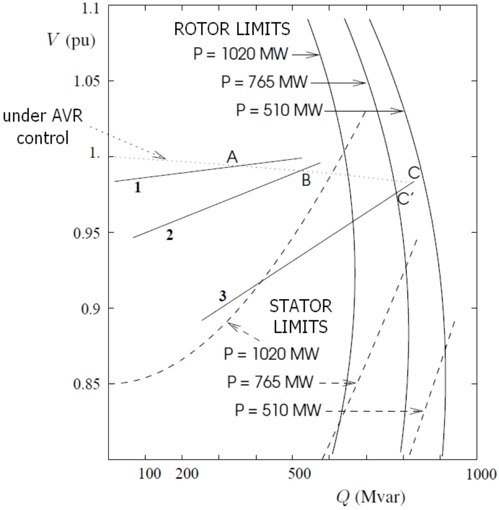
Generator QV curves

Region of admissible operating points in the (Q, V) plane, under constant P

Example of QV curves

50-Hz turbo-generator
rated apparent power: 1200 MVA
rated turbine power: 1020 MW
$X_d = 2.051$ pu
$X_q = 1.966$ pu
saturation taken into account

$I_f = 2671$ A at no load and nominal voltage
$I_f = 8300$ A after OEL activation



- Under Automatic Voltage Regulator (AVR) control:
  - there is a small voltage drop when the reactive power output increases
  - this is due to the proportional control used in AVR
    - a quite common choice
    - voltage drop is significant for low AVR open-loop static gain (e.g. 30-50 pu/pu)
  - in some other AVRs, integral control cancels the steady-state voltage error.

- Under rotor current limit :
  - assuming constant reactive power is an approximation : there is some variation with voltage
  - at least the reactive power limit must be updated with the active power P !

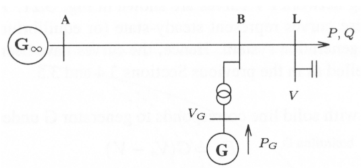
- Under stator current limit :

$$(VI_{max})^2 = P^2 + Q^2 \quad \Rightarrow \quad Q = \sqrt{(VI_{max})^2 - P^2}$$

  - very constraining at low voltage

- Extreme scenario: machine under limit $\rightarrow$ V drops a lot $\rightarrow$ generator tripped by undervoltage protection
  - imposed by proper operation of power plant auxiliaries
  - acts for $V \simeq 0.85 - 0.9$ pu
  - causes to lose *both* P and Q productions ! Larger cascading effects !

Effect of generator reactive limits on maximum load power

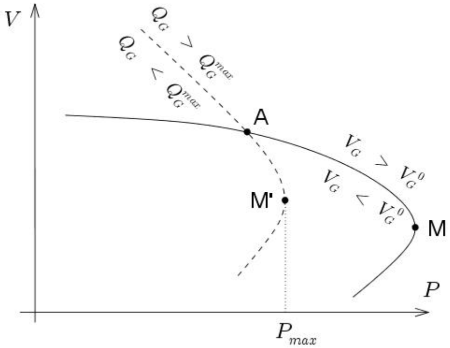


G closer to L than G_∞

P_G remains constant

G controls V_G as long as $Q_G \leq Q_G^{max}$

simple PV/PQ model used for G



- When accounting for the reactive power limit, the maximum load power :
  - is reached at point M', not M !
  - is significantly reduced
  - is generally reached at a higher voltage (more dangerous)
- in most cases voltage stability would not be a problem if generators were unlimited sources of reactive power (i.e. constant voltage sources)
- need for reactive power reserves near the load centers
- impact of Q limit on max P → electrical decoupling does no longer hold !

Illustration with a power flow calculation

$$X_{AB} = 0.2, X_{BL} = 0.005, X_{GB} = 0.02 \text{ pu}, \; r_{GB} = 1.04, \; B_L = 200 \text{ Mvar}$$
$$P_L = 900, P_G = 400 \text{ MW}, \; Q_L = 200, \; Q_G^{max} = 250 \text{ Mvar}, \; V_G = 1.04, V_A = 1.05 \text{ pu}$$

Operating point beyond maximum load power

Trace of Newton iterations:

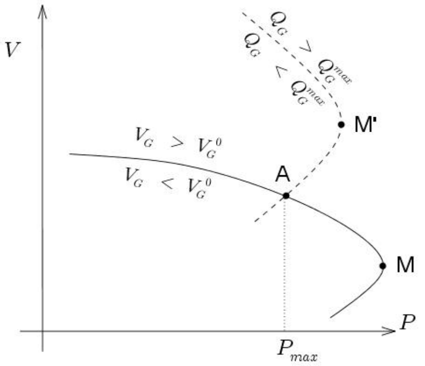
```
  iter    max mismatches :  MW        Mvar
    1                    900.0       445.3
    2                    199.3       339.1
    3                     23.7        28.2
    4                      2.4         1.4
    5                      0.8         0.4
    6                      0.3         0.2
 Gener G : Q =    457.8 > Qmax =    250.0. Switched to PQ type
    6                      0.3       207.8
    7                     50.0        22.3
    8                    258.6        19.2
    9                    140.2        11.3
   10                    304.6        37.6
```

divergence of Newton iterations after the generator reactive limit is enforced.

Effect of generator reactive limits - another situation

Same system

respective position of the PV curves is different



The maximum load power:

- is not reached at point M, where reactive capability of G is exceeded (would cause the OEL to act)
- is not reached at point M', where generator voltage V_G is higher than setpoint V_G^0 (would cause the AVR to regain control)
- is reached at the *breaking point* A, where $V_G = V_g^0$ and $Q_G = Q_G^{max}$

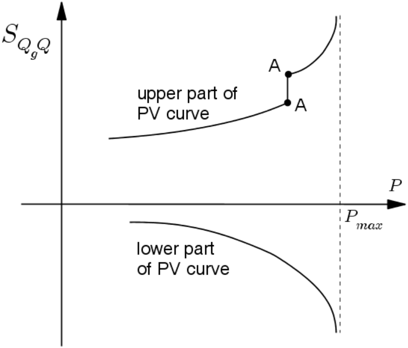
Illustration with a power flow calculation

same data except $Q_G^{max} = 350$ Mvar

```
 iter    max mismatches :  MW        Mvar
   1                     900.0      445.3
   2                     199.3      339.1
   3                      23.7       28.2
   4                       2.4        1.4
   5                       0.8        0.4
   6                       0.3        0.2                      dQg/dQl =  2.45 at bus L
 Gener G : Q =    457.8 > Qmax =    350.0. Switched to PQ type
   6                       0.3      107.8
   7                      13.1        5.0
   8                       5.0        0.4
   9                       0.2        0.1                      dQg/dQl = -2.22 at bus L
Volt of gener G = 1.1418 > setpoint = 1.0500. Back under volt ctl
   9                      32.2      496.0
  10                      20.6       43.3
  11                       1.7        1.5
  12                       0.5        0.4
  13                       0.2        0.1                      dQg/dQl =  2.46 at bus L
 Gener G : Q =    458.4 > Qmax =    350.0. Switched to PQ type
  13                       0.2      108.4
  14                      13.1        5.0
  15                       5.1        0.5
  16                       0.2        0.1                      dQg/dQl = -2.22 at bus L
Volt of gener G = 1.1418 > setpoint = 1.0500. Back under volt ctl
  16                      32.2      496.0
  17                      20.6       43.3
  18                       1.7        1.5 ...
```

Sensitivity behaviour in the presence of generator limits

Discontinuities at the points where a generator limit is enforced



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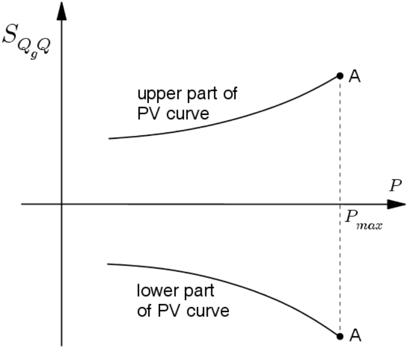
the sensitivity S_{Q_gQ} goes to infinity when passing through the maximum load power point



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the sensitivity S_{Q_gQ} does not go to infinity when passing through the maximum load power point