Optimizing the Generator-Transformer Operation

Relu ILIE

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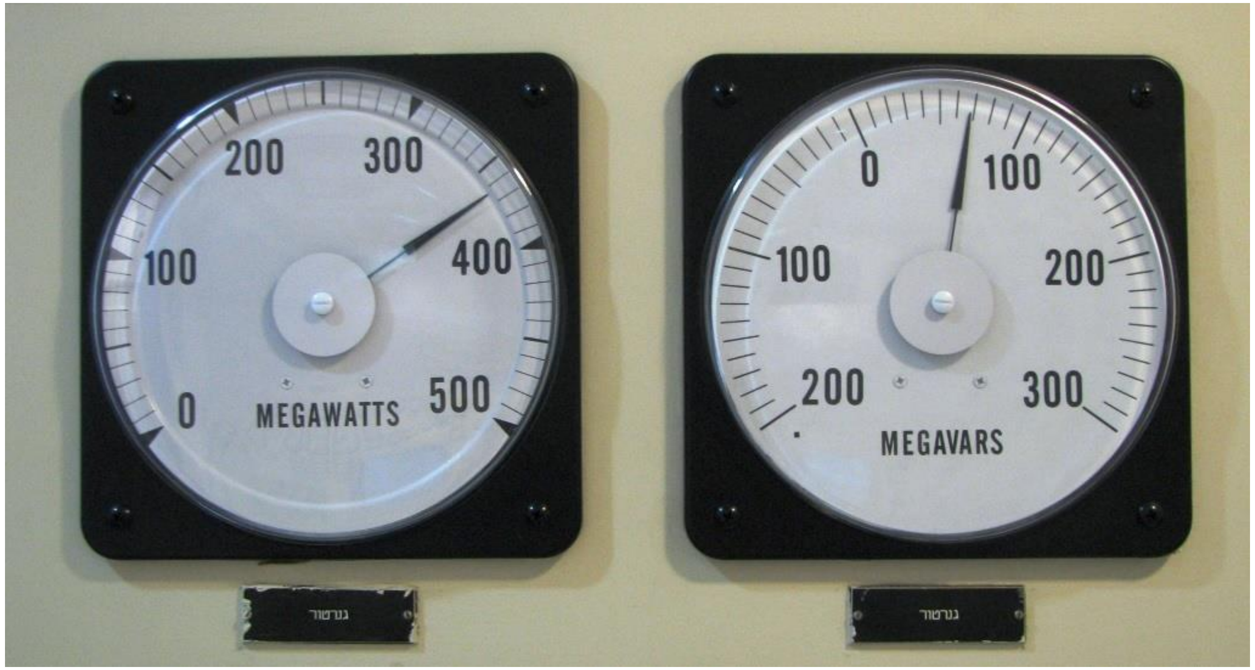
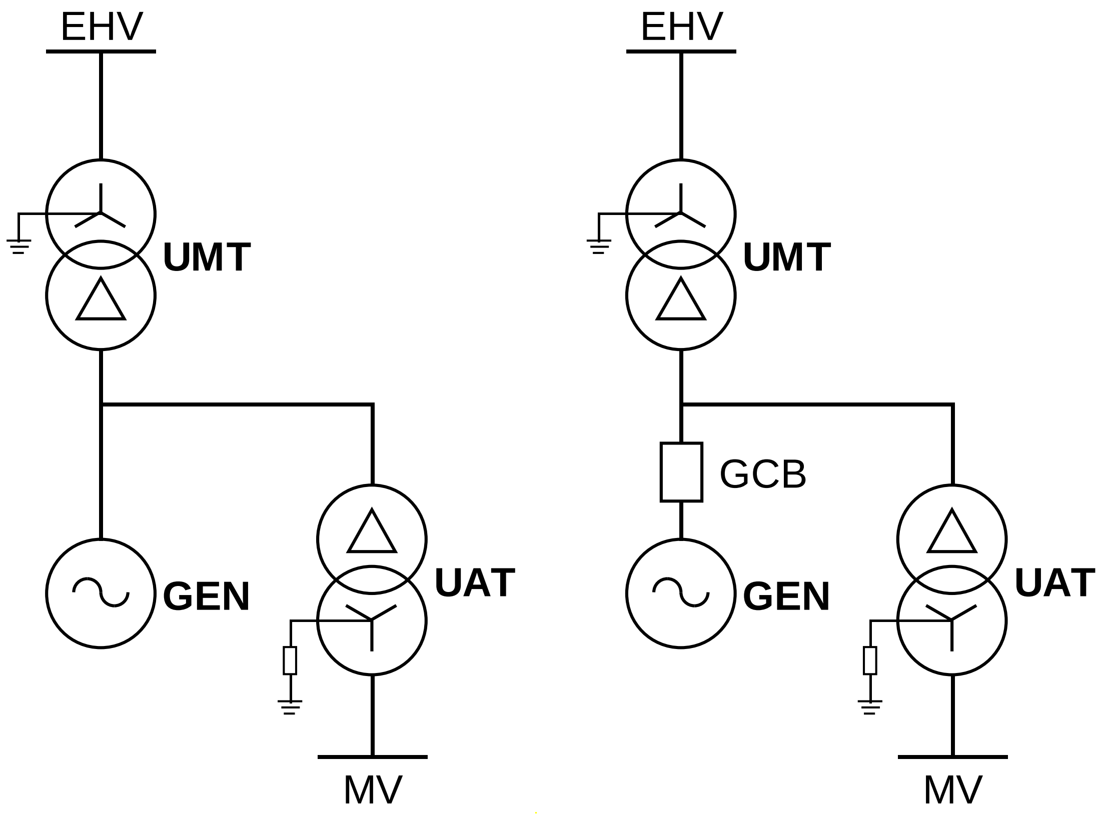


Introduction

- Typical generating unit configurations: block scheme or with generator circuit breaker
- Generator reactive capability in the system relies on unit transformer tap-changer position
- The goal: select the most suitable tap, providing maximum usefulness of generator reactive power
- This is an important *generator related task*, the transformer being a link in generator - network
- Typically, UMT and UAT have de-energized tap-changers, e.g. ±2x2.5% at low current side
- Occasionally, UAT (less common UMT) have on-load tap-changers, for instance ±10x1.25%

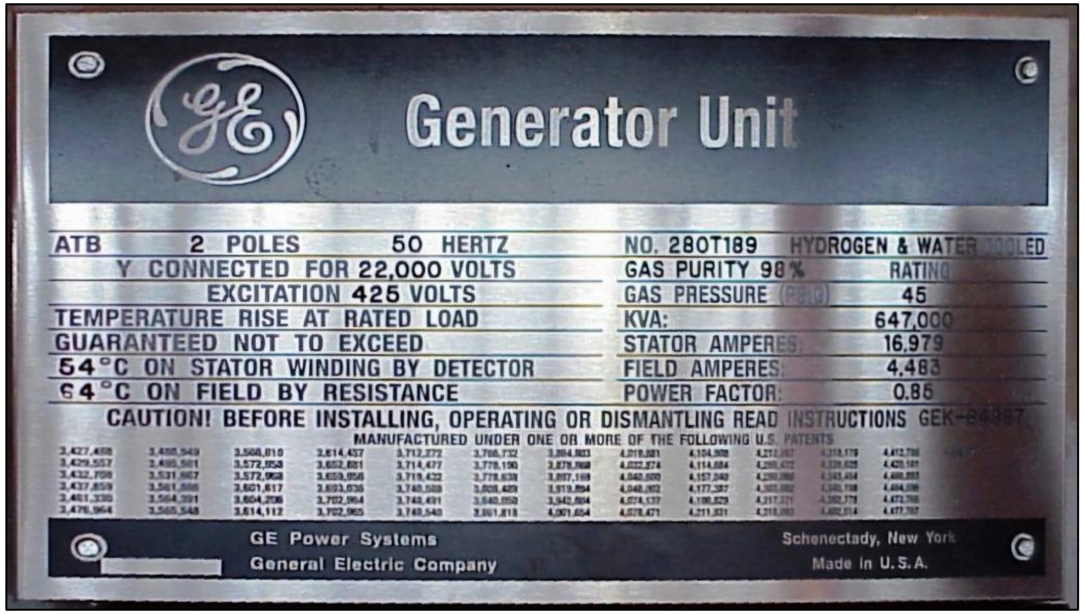


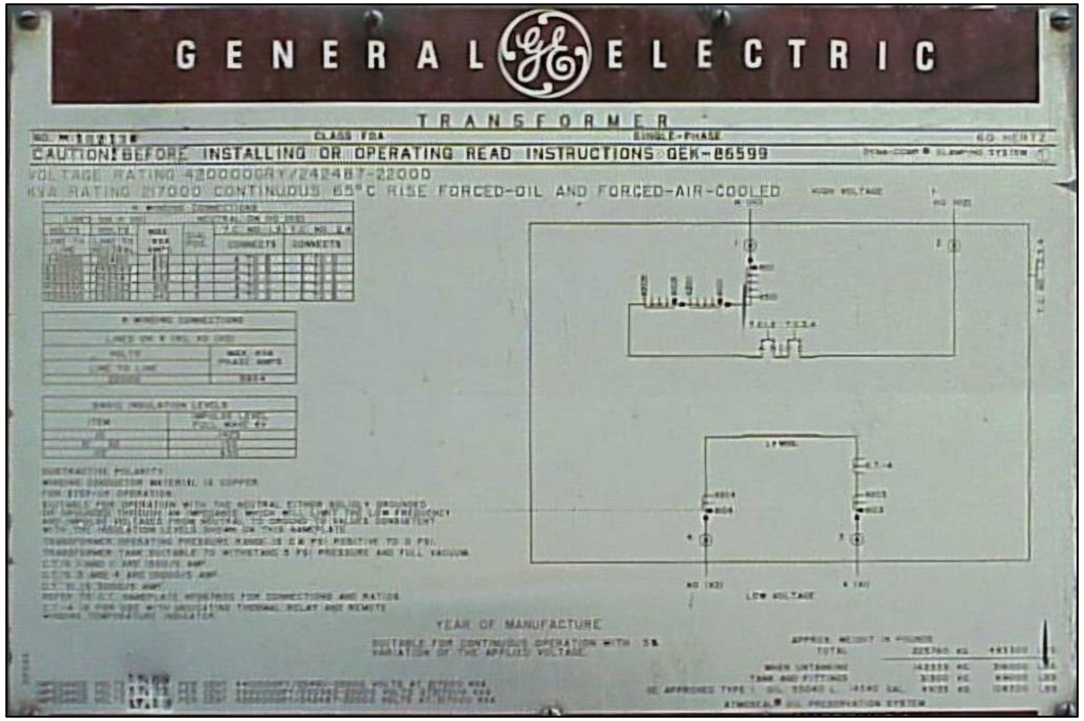
Tap selection methods

- The literature recommends methods to choose the most suitable transformer tap by *interpreting graphically* the unit behavior during various operating regimes
- Ideally, it is desirable for generator to be able to produce MVAR to its overexcited limit when the system voltage is at its lowest expected level, and to absorb MVAR to its underexcited limit when the system voltage is at its highest expected level
- In most cases, it is not possible that a fixed tap will completely fulfill both above requirements, and thus a *compromise* have to be made. Appropriate tap-changer position should be able to meet most likely operating conditions, and preferably uncommon situations too
- Assumption: UMT and UAT parameters have been already set and cannot be changed (MVA, primary and secondary voltages, tap-changer range, impedance)
- Two tap selection methods will be presented, based on generator and transformer equivalent diagrams and equations

Exemplified unit

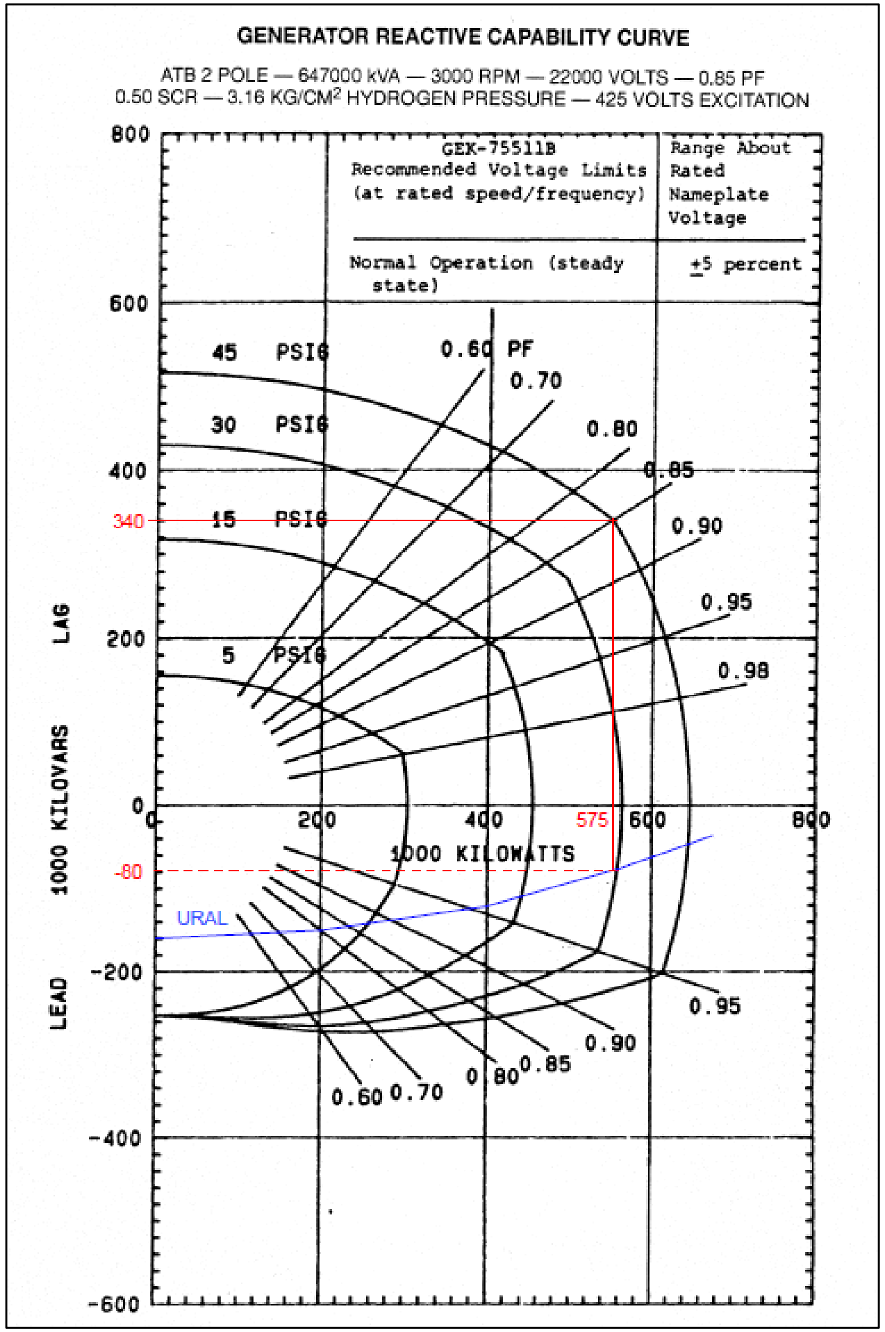
- Both methods exemplified for a 647 MVA, 22 kV generator; 651 MVA, 22/420 kV transformer
- In this particular case, UMT is actually a bank of 3 single-phase 217 MVA transformers
- The power system network has a nominal extra-high-voltage of 400 kV
- The unit has 3 UATs, the auxiliary bus system medium nominal voltage is 6.9 kV





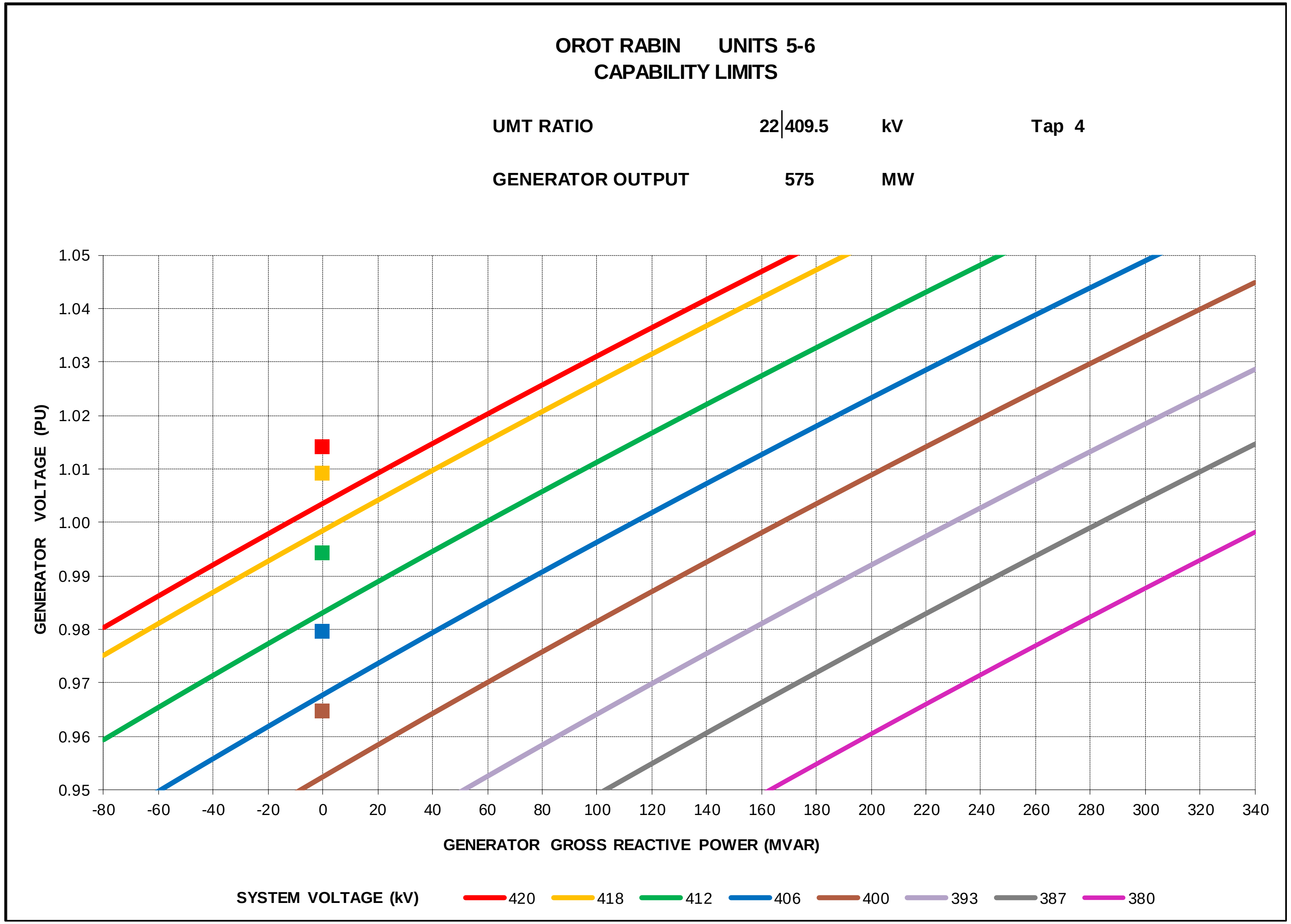
Basic data

- Generator gross active load: rated (matches turbine capability); also checked at operational minimum
- Generator gross reactive power boundaries: from capability curve and underexcited limiter (UEL or MEL or URAL) at a certain gross active load
- Generator voltage limits for continuous operation: 0.95-1.05 pu by IEEE C50.13 and IEC 60034-3
- System voltage at unit connection point according to Grid Code: normal conditions 400-418 kV, abnormal situations 380-420 kV



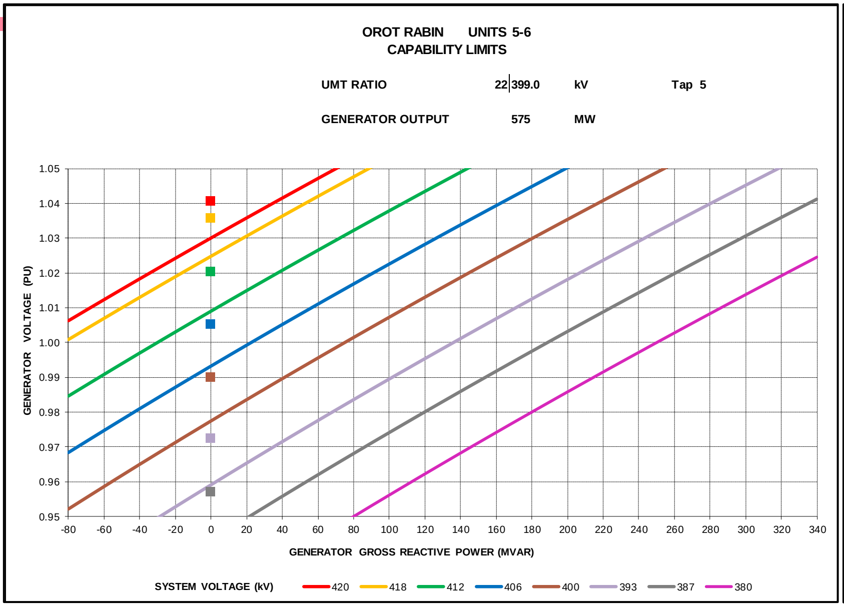
First method chart

- Shows generator gross reactive capabilities within generator voltage limits at various system voltages, certain gross active load and given UMT tap
- Based on guide IEEE C57.116
- Horizontal axis: generator gross reactive power (MVAR). Vertical axis: generator voltage in pu
- Small squares: synchronization capabilities (at zero active and reactive load)

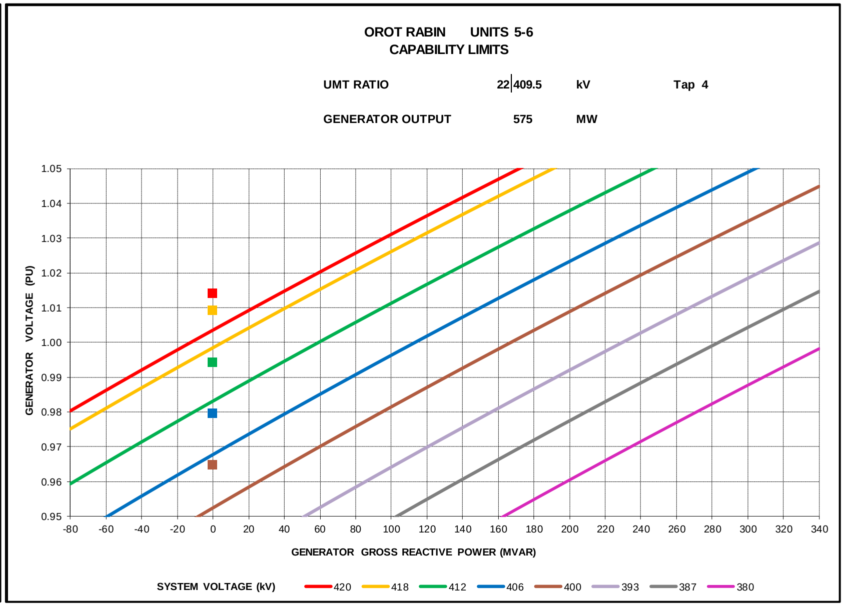


First method analysis

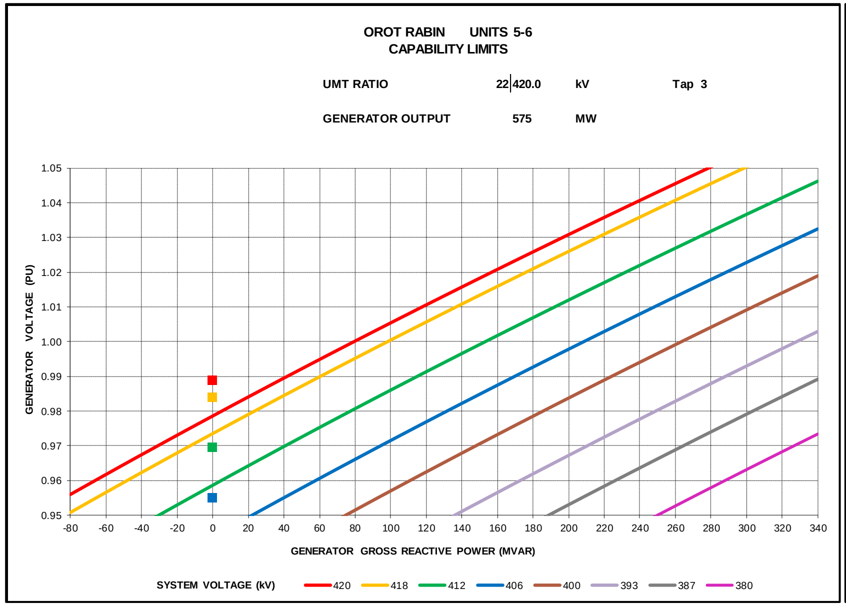
- UMT tap 5: limits delivered reactive power above 400 kV
- UMT tap 4: *best compromise* for usual range 400-418 kV
- UMT tap 3: limits received reactive power below 418 kV
- UMT tap 2 or 1: no received reactive power at any voltage



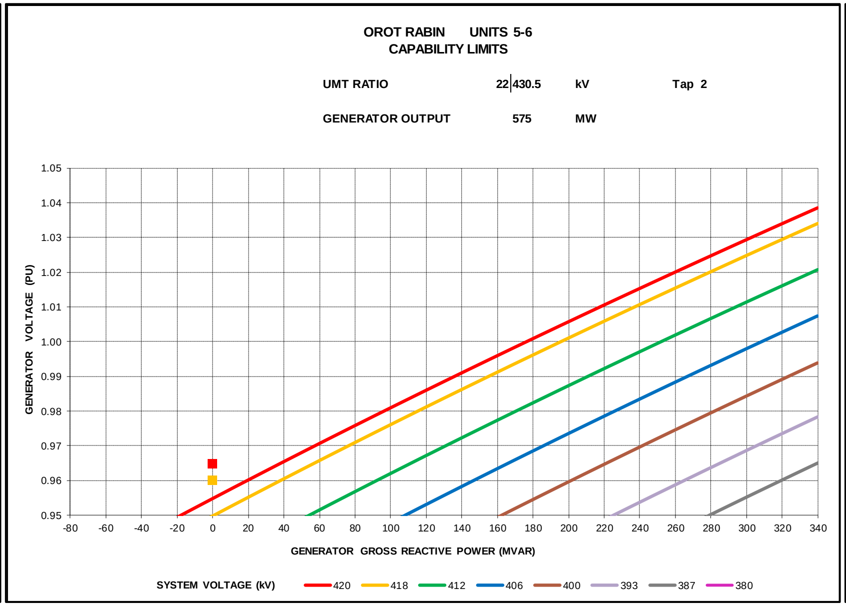
UMT at tap 5 (95.0%)



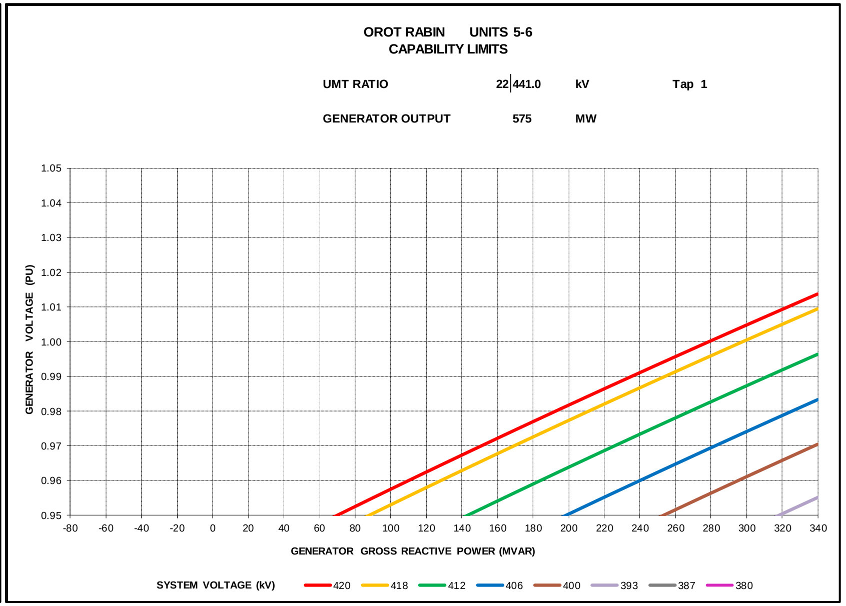
UMT at tap 4 (97.5%)



UMT at tap 3 (100.0%)



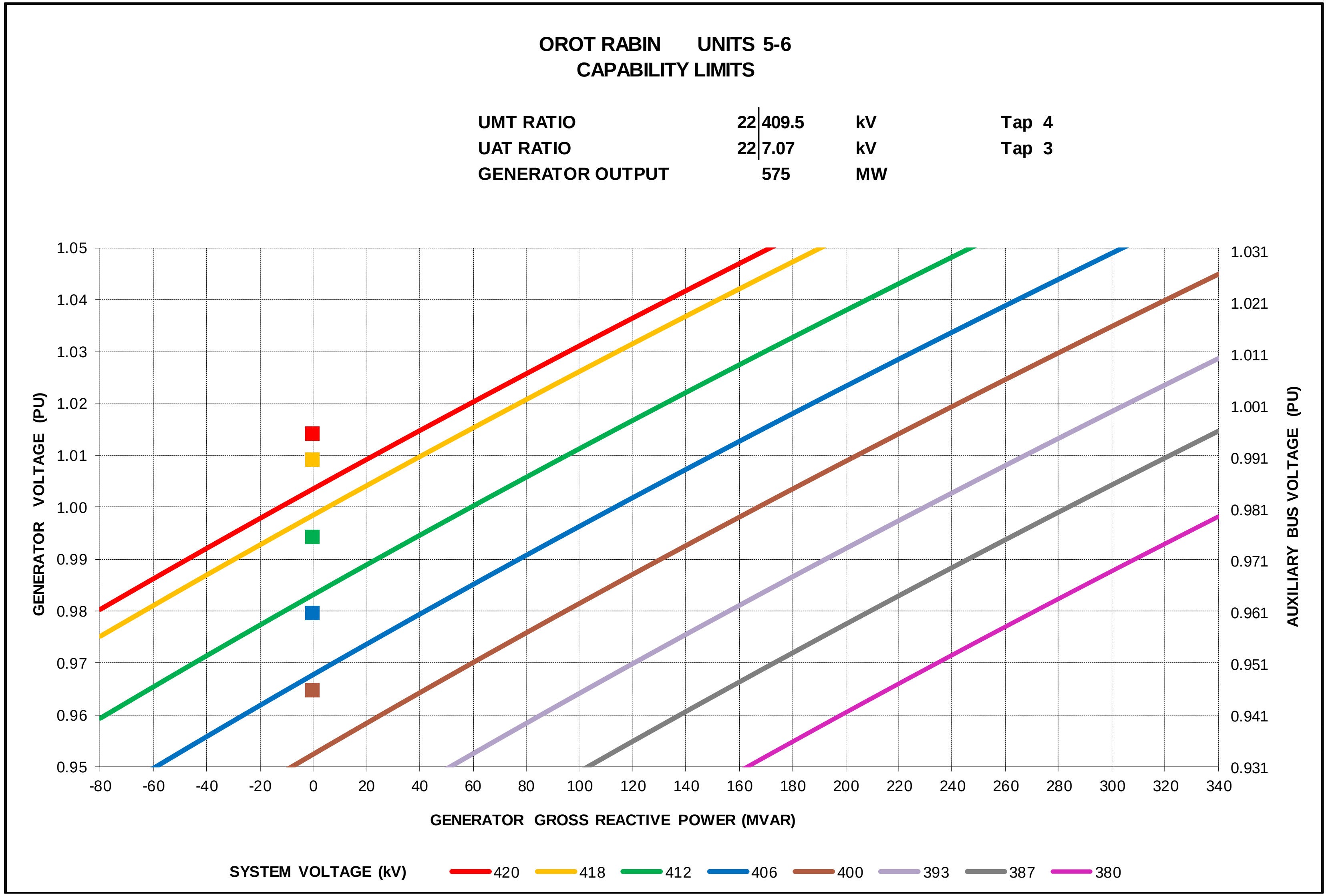
UMT at tap 2 (102.5%)



UMT at tap 1 (105.0%)

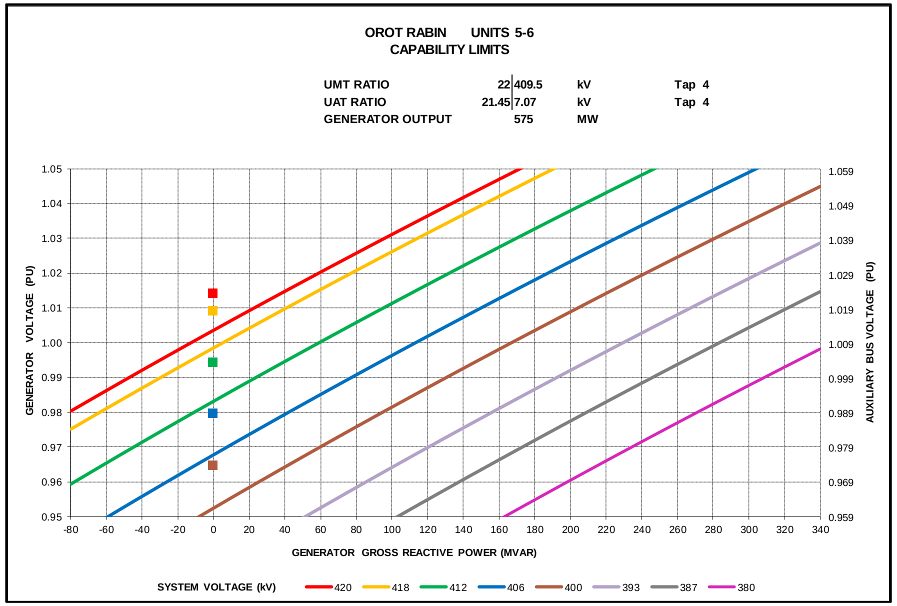
First method chart…

- For UMT at chosen tap 4 and the same gross active load, UAT tap can be further selected
- Secondary vertical axis: auxiliary bus voltage pu
- The sum of all UAT loads to be taken into account

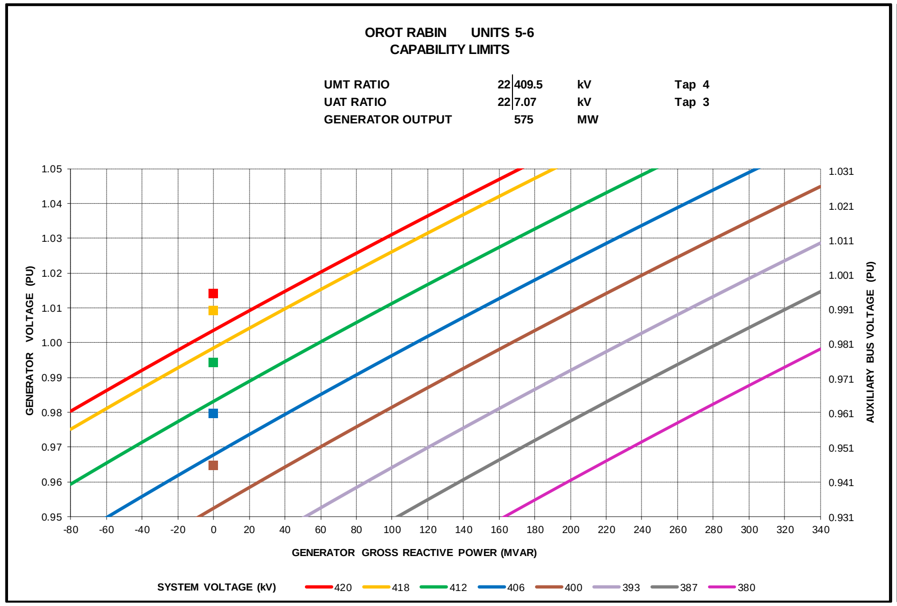


First method analysis…

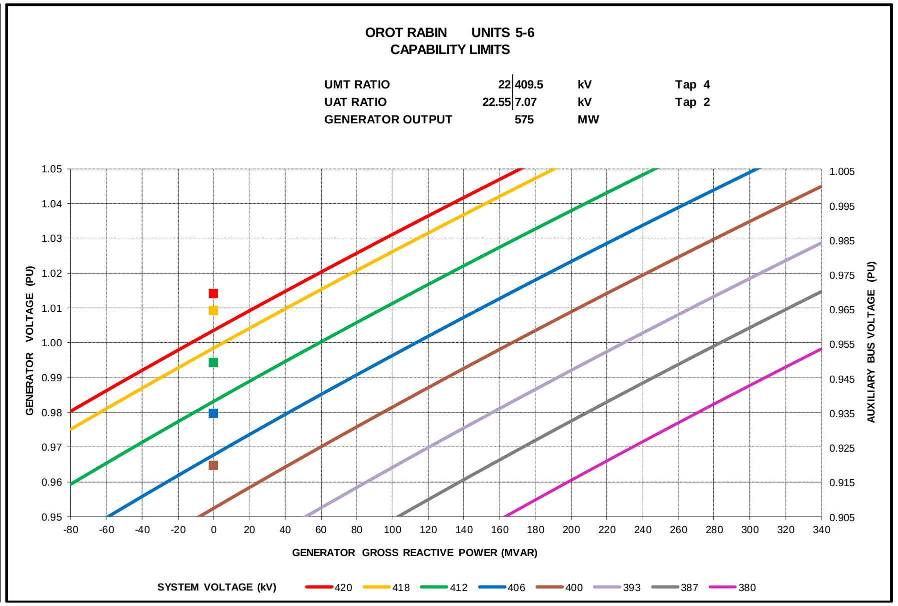
- UAT tap 4: auxiliary bus voltage too high in certain conditions
- UAT tap 3: *preferred* because suitable voltages of 0.93-1.03 pu
- UAT tap 2: bus voltages can drop until about 0.90 pu



UAT at tap 4 (97.5%)



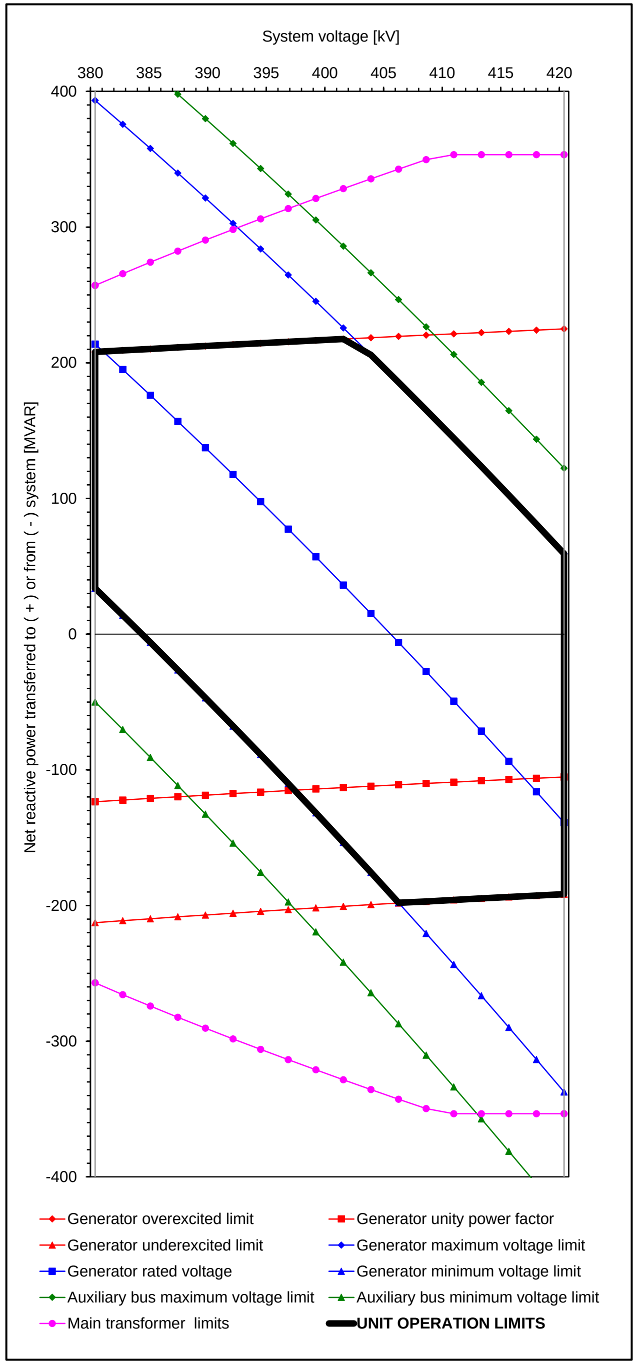
UAT at tap 3 (100.0%)



UMT at tap 2 (102.5%)

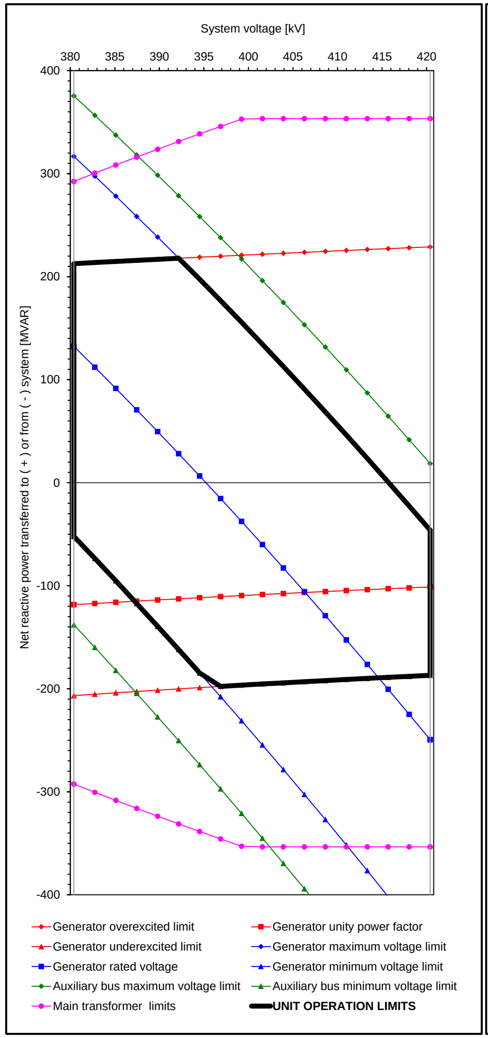
Second method chart

- Shows unit net reactive capabilities (at unit connection point) within system voltage limits, for assumed generator voltage range, certain unit net active load and given UMT tap
- Based on IEEE paper from 1981 and EPRI booklet dated 1987
- Considers more limits: generator voltage, auxiliary bus voltage, generator overexcited / underexcited, main transformer power tapping, transformer over-flux, synchronization capability
- Unit operation range: the most restrictive limitations from all above considerations (thick contour)
- Horizontal axis: system voltage at unit connection point in kV; boundaries: according to Grid Code. Vertical axis: unit net reactive power in MVAR at a certain net active load
- All charts shown for the same case analyzed by the first method

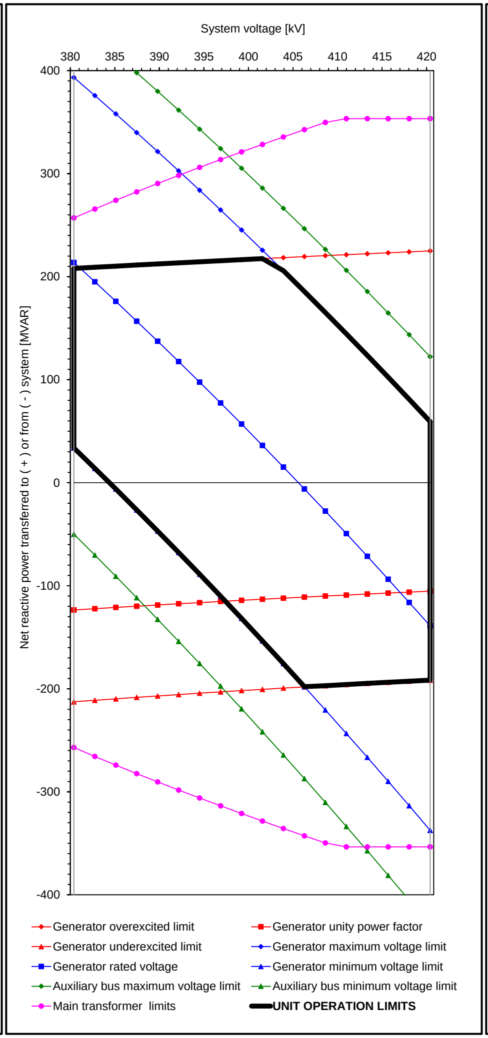


Second method analysis

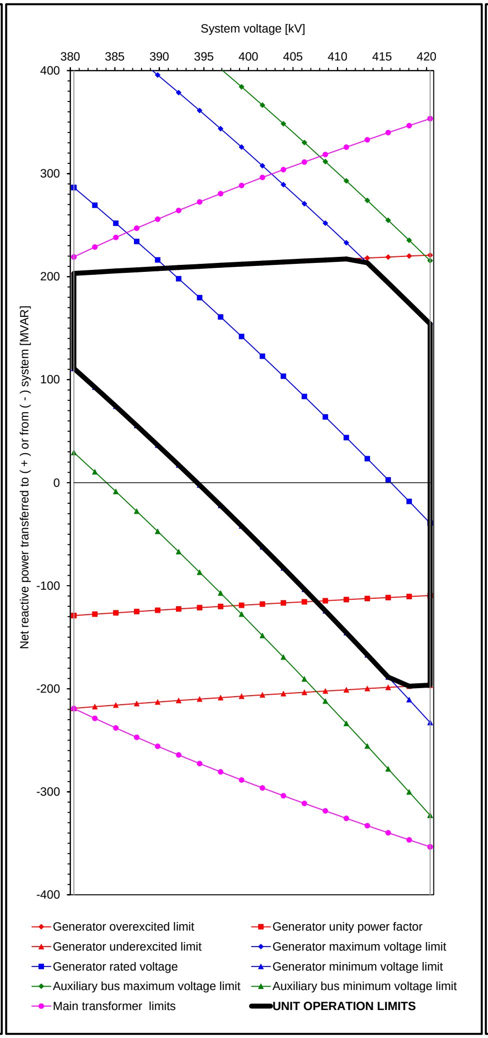
- The conclusion is the same as by first method: tap 4 offers the *broadest operation possibilities*



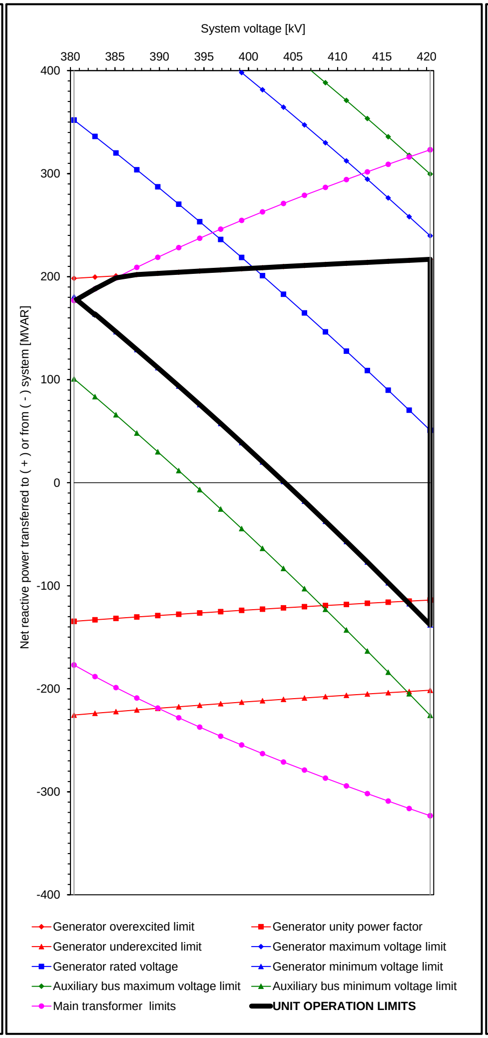
UMT at tap 5 (95.0%)



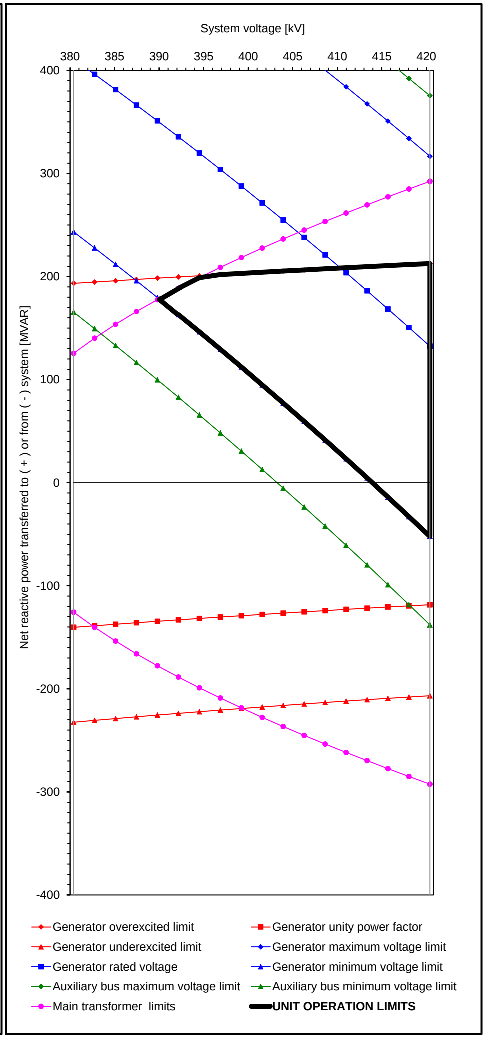
UMT at tap 4 (97.5%)



UMT at tap 3 (100.0%)



UMT at tap 2 (102.5%)

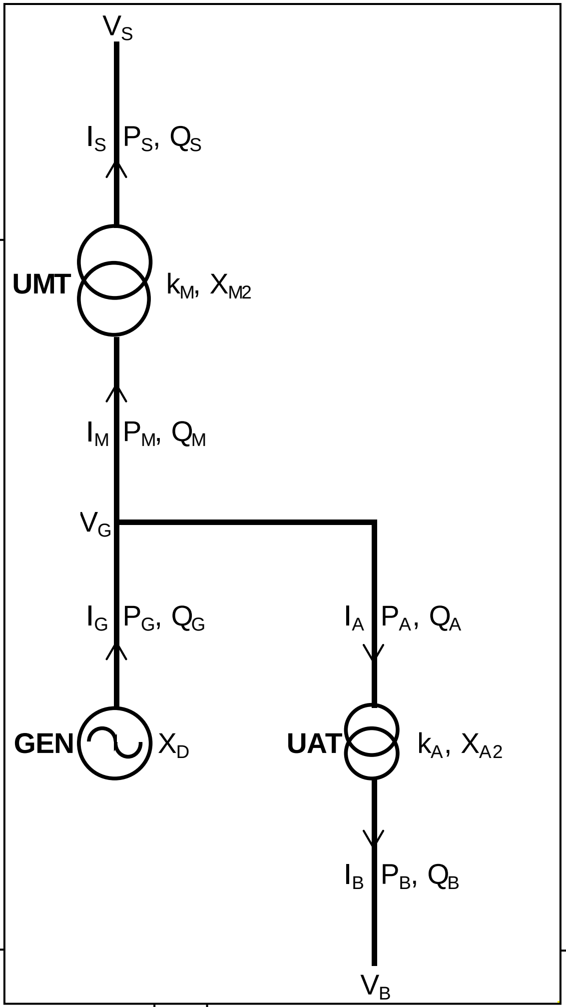


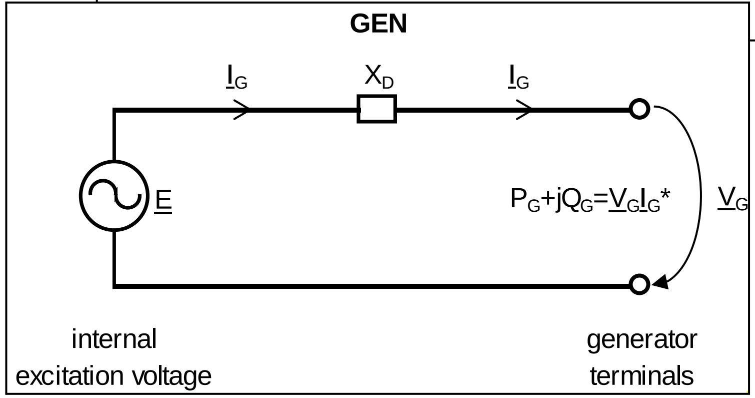
UMT at tap 1 (105.0%)

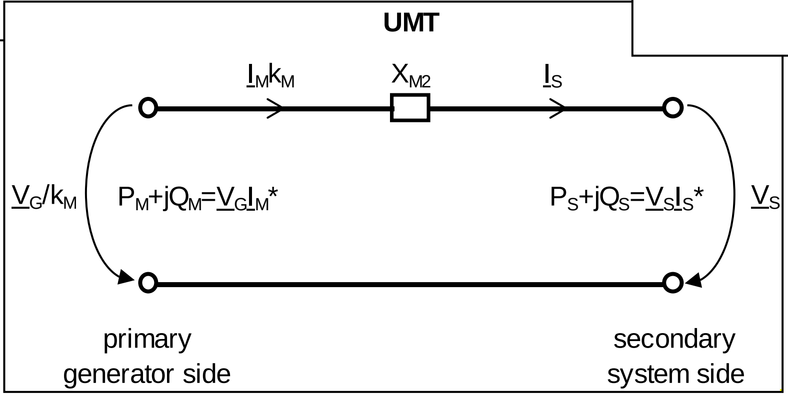
Theoretical calculation

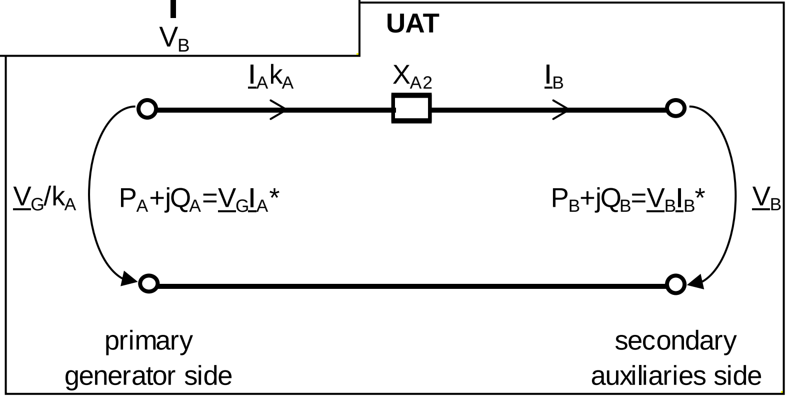
List of Symbols

- I_G – generator current
- I_M, I_S – UMT primary, respectively secondary current
- I_A, I_B – UAT primary, respectively secondary current
- V_G, V_S – generator, respectively system (high/extra high) voltage at unit connection point
- V_B – auxiliary bus (medium) voltage
- P_G, Q_G – active and reactive gross power at generator terminals
- P_M, Q_M – UMT primary active and reactive power
- P_S, Q_S – active and reactive net power transferred to / from system
- P_A, Q_A – UAT primary active and reactive power
- P_B, Q_B – UAT secondary active and reactive power
- k_M, k_A – UMT, respectively UAT ratio (at a specific tap)
- $X_{M\%}$, $X_{A\%}$ – UMT, respectively UAT reactance [percent]
- X_{M2}, X_{A2} – UMT, respectively UAT equivalent reactance viewed from secondary [Ohm]
- X_D – GEN synchronous reactance [pu]
- E - internal generator voltage induced by the field winding flux (excitation voltage)
- (underline text) – used for complex numbers
- * (asterisk symbol) – used for complex conjugate









Excel calculation

Input Data

Fixed rated data (blue):

- S_{MN}, S_{AN} – UMT, respectively UAT rated power [MVA]
- V_{M1N}, V_{M2N} – UMT rated primary voltage, respectively rated secondary voltage [kV]
- V_{A1N}, V_{A2N} – UAT rated primary voltage, respectively rated secondary voltage [kV]
- $X_{M\%}$, $X_{A\%}$ – UMT respectively UAT reactance [percent]
- V_{GN} – GEN rated voltage [kV]
- V_{BN} – rated auxiliary bus voltage [kV]
- S_{GN} – GEN rated apparent power
- Nr_of_UAT connected in parallel (assumed identical)

Range of variable values (green):

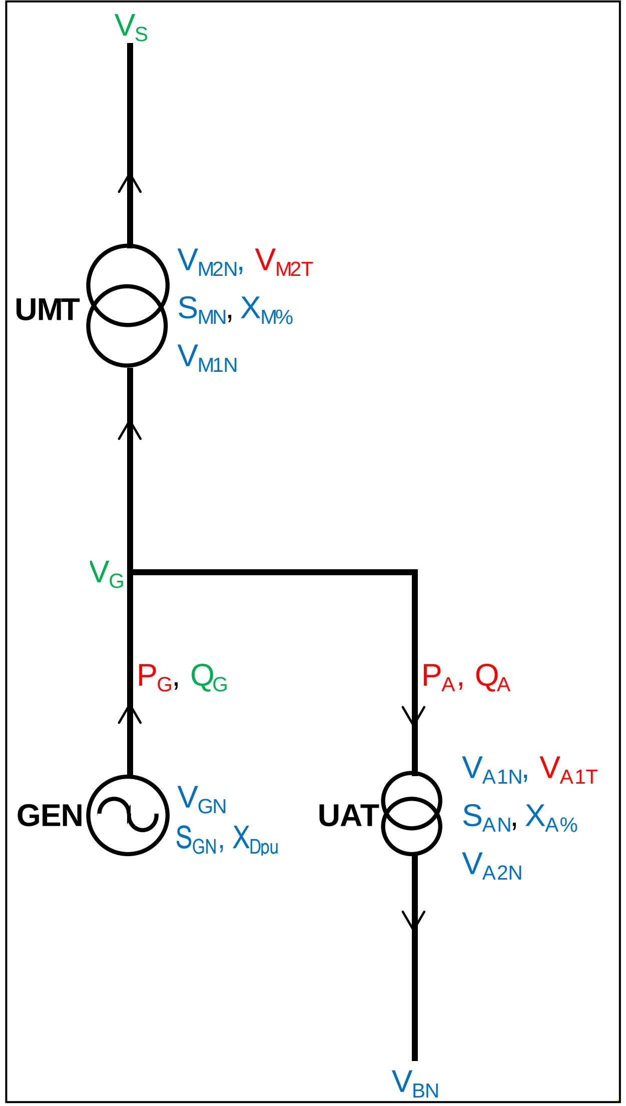
- Q_G – generator gross reactive power range [MVAR]
- V_G – generator terminal voltage range for continuous operation: 0.95 to 1.05 pu
- V_S – system voltage range at unit connection point [kV]

Changeable values (red):

- V_{M2T} – UMT tap secondary voltage [kV] – a particular value for the tap to be analyzed
- V_{A1T} – UAT tap primary voltage [kV] – a particular value for the tap to be analyzed
- P_G – generator gross active power [MW] –a particular value to be analyzed
- P_A, Q_A – UAT primary side active [MW] / reactive [MVAR] loads (total for all UATs)

Output Chart

One obtained for each set of changeable (red) input data



Excel screenshot

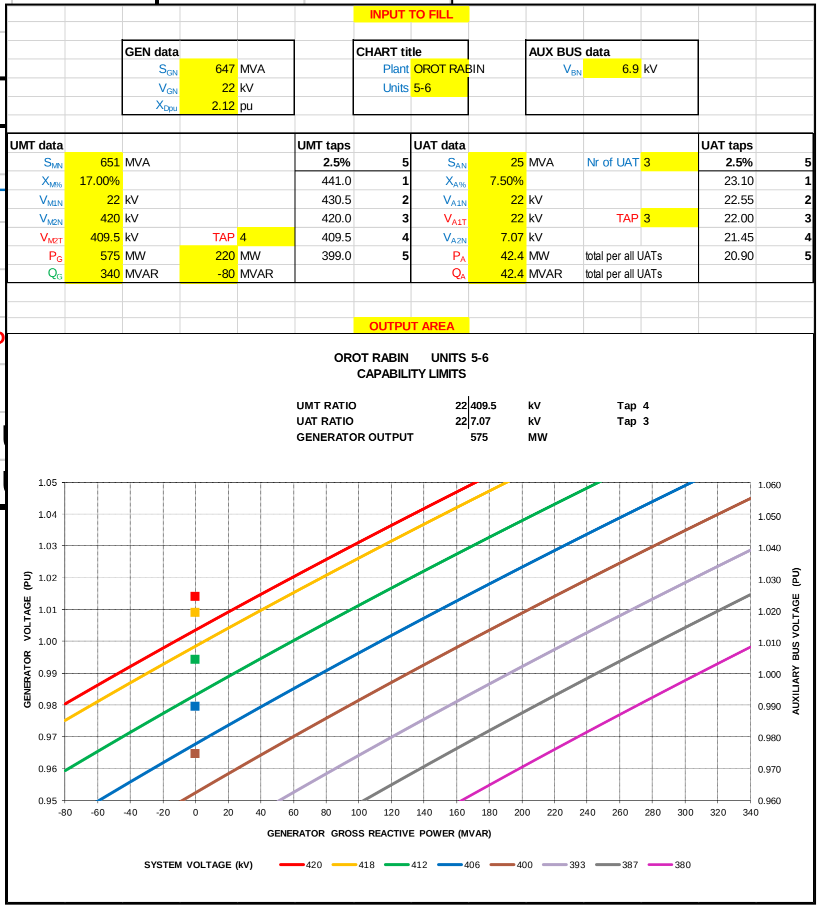
INPUT TO FILL

GEN data		
S_{GN}	647	MVA
V_{GN}	22	kV
X_{Dpu}	2.12	pu

CHART title	
Plant	OROT RABIN
Units	5-6

AUX BUS data		
V_{BN}	6.9	kV

UMT data					UMT taps		UAT data			
S_{MN}	651	MVA			**2.5%**	**5**	S_{AN}	25	MVA	Nr of UAT
$X_{M\%}$	17.00%				441.0	**1**	$X_{A\%}$	7.50%		
V_{M1N}	22	kV			430.5	**2**	V_{A1N}	22	kV	
V_{M2N}	420	kV			420.0	**3**	V_{A1T}	22	kV	TAP
V_{M2T}	409.5	kV	TAP	4	409.5	**4**	V_{A2N}	7.07	kV	
P_G	575	MW	220	MW	399.0	**5**	P_A	42.4	MW	total per all
Q_G	340	MVAR	-80	MVAR			Q_A	42.4	MVAR	total per all



- For a particular unit, several charts should be obtained and analyzed, one for each set of changeable (red) input values, i.e. for each transformer tap-changer position

Conclusions

- A proper main transformer tap-changer position is critical for optimizing the utilization of the desired range of generator reactive capability.
- The selection of most suitable tap should be performed before operating a new generating unit or when the system operation conditions change.
- The presentation describes two tap selection methods and applies them to the same practical case, confirming the same conclusions are obtained.
- The operation experience achieved during about 30 years demonstrates the accuracy of these tap selecting methods in various power plants.
- The calculations have been performed in Excel, a simple readily accessible tool for field engineers; no doubt that more sophisticated tools are available.
- The first method is usually simpler to implement and analyze. The second method is comprehensive, however it requires a larger amount of work.

Thank you!

Please email me if you are interested in my detailed paper on this subject

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