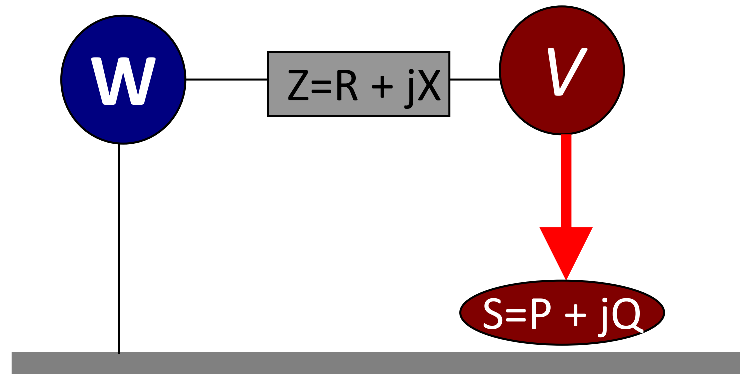
The Operational Solution versus **N**on-Operational Solutions

Which Solutions are Really Possible in a Real Network?

Operational and Non-Operational

- By ‘Operational Solution’ we mean the kind of solution that all the control devices in the network aim to stabilize.
- Most voltage control devices in power networks work by injecting reactive power when detecting that the voltage decreases. This is indeed the physical behavior under a normal operating conditions, i.e. the voltage magnitude grows when injecting more reactive power.
- If we had a solution where the voltage decreased when injecting reactive power, the voltage control devices would be unstable: under the slightest voltage drop, they would inject more reactive power, causing the voltage to decrease further, thus provoking a voltage collapse.
- These kind of solutions are termed non-operational because they can not survive in actual electrical networks, as they are designed to operate the other way around.

Two Bus Case



- Ohm's law $V - W = ZI = Z\frac{S^*}{V^*}$
- Define $U \equiv \frac{V}{W}; s \equiv S\frac{Z}{W * W^*}$
- Rewrite Ohm's law as: $U = 1 + \frac{s}{U^*}$

Solutions of the Two Bus Case

- Multiply by U*: $U * U^* = |U|^2 = U^* + s$
- Separate imaginary and real parts: $|U|^2 = U_R + s_R; U_I = s_I$
- Second order eqn. for U_R: $U_R^2 - U_R + s_I^2 - s_R = 0$
- Where $s_R = \dfrac{RP + XQ}{|W|^2}; s_I = \dfrac{XP - RQ}{|W|^2}$
- Solutions: $U_R = \dfrac{1}{2} \pm \sqrt{\dfrac{1}{4} + \sigma_R - \sigma_I^2}$ provided $\dfrac{1}{4} + s_R - s_I^2 \geq 0$

$$U = \left(\frac{1}{2} \pm \sqrt{\frac{1}{4} + \sigma_R - \sigma_I^2} \right) + j\sigma_I$$

Behavior of the Two Solutions

$$U = \left(\frac{1}{2} \pm \sqrt{\frac{1}{4} + \sigma_R - \sigma_I^2} \right) + j\sigma_I$$

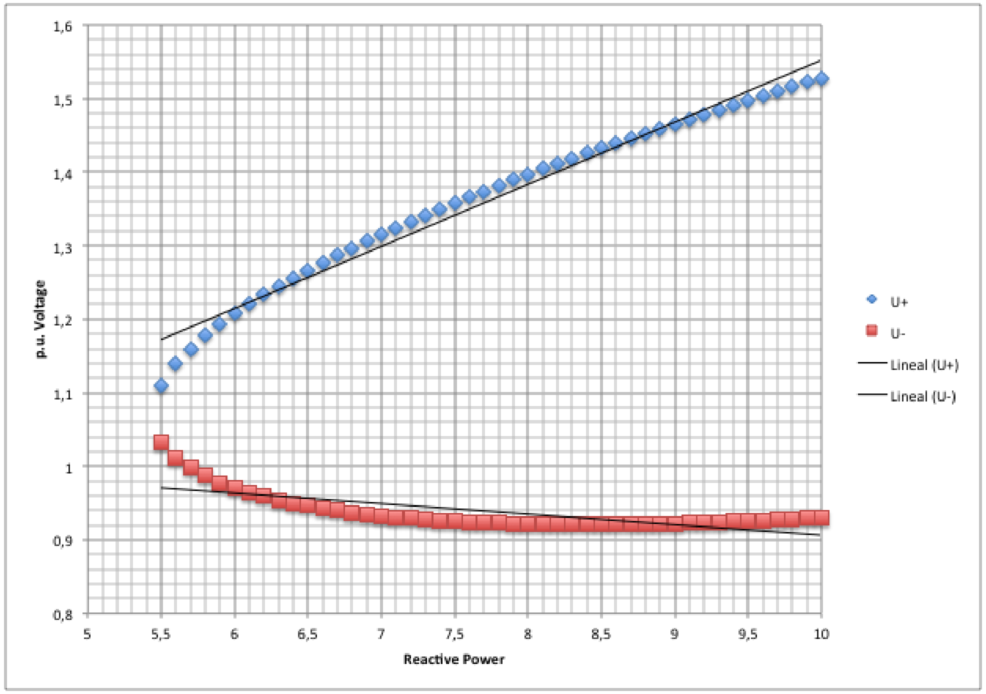
Consider the case where R=X=0, in this case σ=0 and the two solutions reduce to:

- $U_+ = 1$
- $U_- = 0$

Where the sub-indexes indicate the choice of the sign in the square root. The behavior one seeks for a solution is clearly the one displayed by U_+ .

The graph on the right displays the behavior of these two solutions as Q varies for the following values of the parameters:
R=0.01, X=0.1, P=10MW

In the solution U_+ it becomes apparent that the voltage increases with Q, whereas the opposite happens to U_- .



Helm Links to the Operational Solution

- The power series used by HELM are of the form:

$$V_i(s) = V_{sw} + sV_i^1\left[0\right] + \ldots + s^n V_i^n\left[0\right] + \ldots ; i = [1,N]$$

- Where V_{sw} stands for the swing voltage; this guarantees that the solution is linked to U_+ at each node.
- For PV nodes a conceptually similar embedding condition is used, to fulfill the constraint on |V| at these nodes.
- This singles out from all the possible solutions the unique solution that is compatible with the voltage controls existing on the electric network.
- Thus the solution HELM provides is precisely the operational solution.

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