Offshore Wind Farm Optimization

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Bachelor's Degree in Industrial Technologies and Economic Analysis

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Contents

Motivation

- Variable renewable energy like wind and solar is becoming increasingly prevalent in the electrical grid.
- The presence of these sources is leads to unwanted effects in the grid such as overvoltages and voltage imbalances.
- Historic solutions are not well equipped to deal with these effects and especially the fast response times required.
- New power electronics based solutions, such as the unified power quality converter (UPQC), are investigated to solve this problem.

Goals

- To analyze voltage spread of distribution grid with high penetration of solar.
- To develop a dynamic model of the UPQC, including all required controllers.
- To develop an equivalent static model of the UPQC and validate its behaviour with the dynamic model.
- To propose design methodology for the converter sizing making use of the developed tools.
- To show behaviour of the converter over sample days using different design criteria.

Transmission system design

Converters are prone to be saturated during short-circuits (I_{max} is reached).

Table 1: Possible operating states of the converters in grid-following mode.

Converter State	**PQ**	**PV**
USS	$P,\ Q$	$P,\ V$
PSS	$Q,\ I_{max}$	$V,\ I_{max}$
FSS	$P=0,\ I_{max}$	$P=0,\ I_{max}$
DIS	$P=0,\ Q=0$	$P=0,\ Q=0$

Elements modelling

Traditional power flow:

$$\begin{pmatrix} \Delta f_P \\ \Delta f_Q \end{pmatrix} = -\begin{pmatrix} \frac{df_P}{d\theta} & \frac{df_P}{d\nu} \\ \frac{df_Q}{d\theta} & \frac{df_Q}{d\nu} \end{pmatrix} \begin{pmatrix} \Delta\theta \\ \Delta\nu \end{pmatrix}. \tag{1}$$

Extended Newton-Raphson considering current saturation:

$$\begin{pmatrix} \Delta f_P \\ \Delta f_Q \\ \Delta f_{I^2} \end{pmatrix} = -\begin{pmatrix} \frac{df_P}{d\theta} & \frac{df_P}{d\nu} \\ \frac{df_Q}{d\theta} & \frac{df_Q}{d\nu} \\ \frac{df_{I^2}}{d\theta} & \frac{df_{I^2}}{d\nu} \end{pmatrix} \begin{pmatrix} \Delta\theta \\ \Delta\nu \end{pmatrix}, \tag{2}$$

where the residuals are:

$$\begin{cases} \Delta f_P = -P_{\text{set}} + \Re([V]Y^*V^*), \\ \Delta f_Q = -Q_{\text{set}} + \Im([V]Y^*V^*), \\ \Delta f_{I^2} = I_c I_c^* = -I^2_{c,max} + (YV - [V^*]^{-1}S^* - I_l) \cdot (YV - [V^*]^{-1}S^* - I_l)^*. \end{cases} \tag{3}$$

New bus types

New categories of buses emerge:

Table 2: Traditional types of buses and mapping to new buses depending on the converter state.

Converter State	**PQ Control**	**PV Control**
USS	PQ	PV
PSS	QI	VI
FSS	PI	PI
DIS	PQ	PQ

Costs

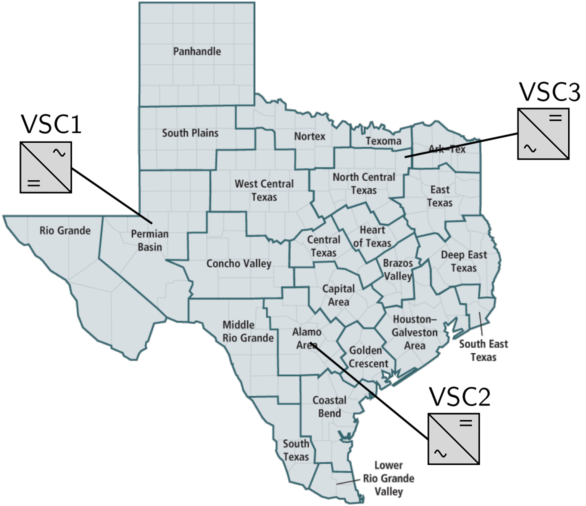


Figure 1: Approximate location of the three converters.

Summary

Table 3: Power flow results for the converters under normal conditions.

VSC	State	v	θ (°)	$\lvert I \rvert$	P	Q	$\lvert S \rvert$
vsc1	USS	1.0073	-40.7924	5.8017	-5.0000	3.0260	5.8443
vsc2	USS	1.0050	-63.9565	1.3882	-1.0000	0.9731	1.3953
vsc3	USS	1.0200	-48.6301	6.0529	6.0000	1.4580	6.1746

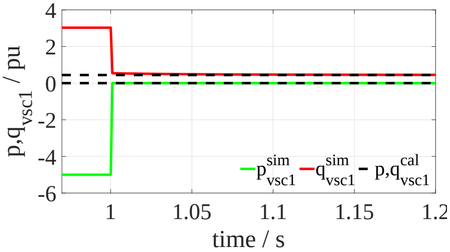
Table 4: Short-circuit results for the converters with $\underline{Z}_f = 0.002j$.

VSC	State	v	θ (°)	$\lvert I \rvert$	P	Q	$\lvert S \rvert$
vsc1	FSS	0.0633	-14.1576	7.0000	0.0000	0.4431	0.4431
vsc2	USS	0.9997	-63.3836	1.3958	-1.0000	0.9732	1.3954
vsc3	USS	0.9997	-46.1701	6.1764	6.0000	1.4582	6.1746

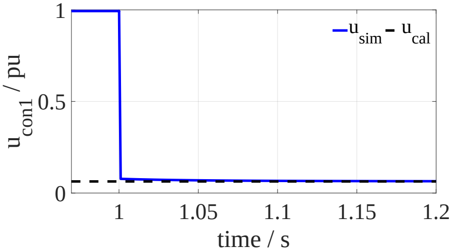
Table 5: Short-circuit results for the converters with $\underline{Z}_f = 0.05j$.

VSC	State	v	θ (°)	$\lvert I \rvert$	P	Q	$\lvert S \rvert$
vsc1	PSS	0.6423	-34.1962	7.0000	-3.1009	3.2557	4.4962
vsc2	USS	1.0050	-63.9565	1.3882	-1.0000	0.9696	1.3928
vsc3	USS	1.0200	-48.6301	6.0529	6.0000	1.4453	6.1716

Results validation



(a) VSC1 power injections.



(b) Fault voltage.

Figure 2: Dynamic simulation with PSS/E for a severe fault with $\underline{Z}_f = j0.002$ pu.

Comparison with PSS/E

Steady-state calculations:

Table 6: Steady-state short-circuit results with the proposed method and PSS/E.

$\underline{Z}_f$ \ I_{sc}	**Proposed method**	**PSS/E VSCs as generators**	**PSS/E VSCs as FACTS**
$j0.05$	12.75	13.40	12.17
$j0.002$	31.40	32.57	25.91

PSS/E dynamic simulation:

Table 7: Comparison of efficiency with PSS/E dynamic simulation.

t_{sim} **after fault (s)**	**Calculation time (s)**	**Error** $\lvert u_{sample} - u_{cal} \rvert$ **(pu)**
0.3	1.43	42×10^{-3}
1	3.52	19.8×10^{-3}
2	6.81	6.5×10^{-3}
3	10.07	1.6×10^{-3}
4	13.14	$< 0.1 \times 10^{-3}$
Proposed method	0.085	6.17×10^{-11}

Conclusions

✓ To analyze voltage spread of distribution grid with high penetration of solar.
✓ To develop a dynamic model of the UPQC, including all required controllers.
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Next Steps

- Find optimal shunt converter current calculation
- Extend static model to state space to provide pseudo dynamic behaviour
- Create a voltage limit condition dependent on the load

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