APPLICABILITY OF DROOPS IN LOW VOLTAGE GRIDS

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ABSTRACT

Remote electrification with island supply systems, the increasing acceptance of the microgrids concept and the penetration of the interconnected grid with distributed energy resources (DER) and renewable energy resources (RES) require the application of inverters and the development of new control algorithms.

One promising approach is the implementation of conventional f/U-droops into the respective inverters, thus down scaling the conventional grid control concept to the low voltage grid. By this methodology superior system architecture is enabled, providing redundancy, enabling expandable distributed systems and avoiding vast communication expense. With the development of the control algorithm *selfsync* ^{TM} the operability of droops in inverters has been proven.

Being based on conventional droops this control concept can be derived from inductively-coupled voltage sources. A voltage source combined with an inductance represents a high voltage line with a stiff grid or a synchronous machine (generator). Here the reactive power is related with the voltage and the active power with the phase shift or respectively with the frequency. This changes with the low voltage line and its resistive character, where reactive power is related with the phase shift and active power with the voltage. Nevertheless, the droop concept is still operable due to its “indirect operation”, which will be outlined below.

DROOP CONTROL

In expandable distributed inverter systems and in distribution systems with grid-tied inverters communication and/or extra cabling can be overcome if the inverters themselves set their instantaneous active and reactive power. In [2] a concept has been developed using reactive power/voltage and active power/frequency droops for the power control of the inverters. The droops are similar to those in utility grids. The supervisory control just provides parameter settings for each component, which comprise the idle frequency, the idle voltage, the slopes of the droops and basic commands. By this way, expensive control bus systems are replaced by using the grid quantities voltage and frequency for the co-ordination of the components. Such approach results in the following features:

- simple expansion of the system,
- increased redundancy, as the system does not rely on a vulnerable bus system,
- for optimisation a simple bus system is sufficient,
- a simplified supervisory control but
- more complex control tasks in the components.

Additional redundancy in power supply systems can be achieved by exclusively using voltage controlled inverters (VCI) in parallel or even using VCIs for grid connection. This approach avoids the master/slave operation. In fact, all VCIs form the grid.

The active power P_{inv} and the reactive power Q_{inv} of the voltage sources – here representing a grid connected inverter - can be calculated as follows:

$$P_{inv} = \frac{U_{inv} \cdot U_{grid}}{\omega_N L} \sin \delta \qquad (1)$$

$$Q_{inv} = \frac{U_{inv}^2}{\omega_N L} - \frac{U_{inv} \cdot U_{grid}}{\omega_N L} \cos \delta \qquad (2)$$

A phase shift δ between two voltage sources causes active power transmission. Reactive power transmission is due to the voltage difference U_{inv} - U_{grid}. Assuming standard values for the inductance L results in very sensitive systems, where even smallest deviations of the phase and the magnitude cause high currents between the inverters. This sensitivity is the reason why fixed frequency and fixed voltage controlled inverters can't operate in parallel. There is always a voltage difference due to tolerances of the sensors, references, temperature drift and ageing (e. g. 1 – 5 %) and also crystals are not equal. The frequency errors of the crystals are integrated over the time, resulting in hazardous angle differences (s.Eq. 1).

It has been proposed [2] a control with f to be a function of P: the VCI output power is measured and this quantity is used to adjust its output frequency (s. Fig. 1).

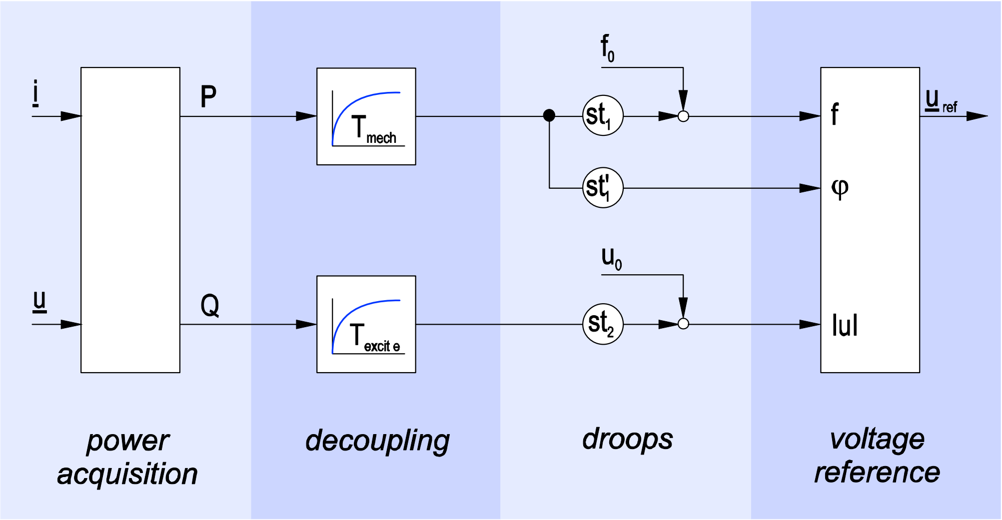


Figure 1: Control approach *selfsync*^{TM} by ISET e.V., Kassel, Germany

IMPLICATIONS OF LINE PARAMETERS

Power transmission in the low voltage grid

Assuming inductively-coupled voltages sources for representing the droop controlled inverters and the distribution system would be only correct for the high voltage level. A medium voltage line has mixed parameters and the low voltage line is even predominantly resistive.The active power P_{inv} and the reactive power Q_{inv} of resistively-coupled voltage sources - here an inverter and a grid – can be calculated as follows with the notation according to Fig. 3.1:

$$Q_{inv} = \frac{U_{inv} \cdot U_{grid}}{R_{line}} \sin\delta \tag{3}$$

$$P_{inv} = \frac{U_{inv}^2}{R_{line}} - \frac{U_{inv} \cdot U_{grid}}{R_{line}} \cos\delta . \tag{4}$$

Eq. 4 reveals that the active power flow and the voltage is linked in the low voltage grid. A phase difference between the voltage sources causes reactive power flow (s. Eq. 3). This fact suggests to use active power/voltage and reactive power/frequency droops - hereinafter called “opposite droops” - in the low voltage grid instead of reactive power/voltage and active power/frequency droops - hereinafter called “conventional droops”.

Comparison of droop concepts for the low voltage level

In the following the advantages and disadvantages of using conventional or opposite droops on the low voltage level are discussed. The boundary conditions for applying conventional droops in low voltage grids will be outlined afterwards.

In the low voltage grid the voltage profile is linked with the active power distribution. Reactive power is not suited for voltage control. From a system's view the voltage control and the active power dispatch are the major control issues. Table 1 shows pros and cons of using these two droop concepts.

Table 1: Comparison of Droop Concepts for the Low Voltage Level

	Conventional droop	*Opposite droop*
Compatible with HV-level	yes	no
Compatible with generators	yes	no
Direct voltage control	no	yes
Active power dispatch	Yes	no

As one can see from the Table 1 the only advantage of using the opposite droops is the direct voltage control. But if one would control the voltage this way, no power dispatch would be possible. Each load would be fully supplied by the nearest generator. As this generally is not possible, voltage deviations would remain in the grid. Using conventional droops results in connectivity to the high voltage level, allows power sharing also with rotating generators and a precise power dispatch. The voltage deviations within the grid depend on the grid layout, which is today's standard.

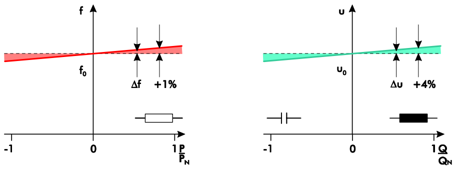
INDIRECT OPERATION OF DROOPS

Basically, the conventional droop is operable in the low voltage grid due to the generator's voltage variability by means of exchanging reactive power. The reactive power of each generator is tuned the way that the resulting voltage profile satisfies the desired active power distribution. In the low voltage grid the reactive power is a function of the phase angle (s. Eq. 3). This is adjusted with the active power / frequency -droop. The control sense of the entire loop has to be consistent. Four stable operating points result, two of which make sense, depending on the slopes of the droops (s. Table 2).

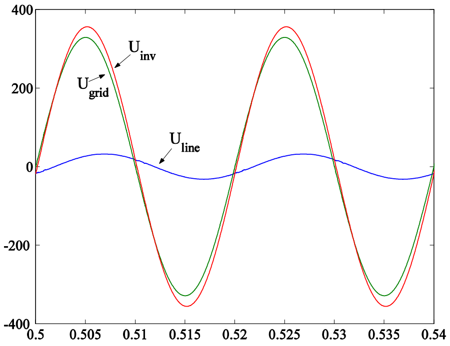
Table 2: Stable Operating Points of Conventional Droops in the Low Voltage Grid

case	*Description*	p_{droop}	q_{droop}	k	*comment*
1	inverse conv.	pos.	pos.	1	allowed
2	conv.	neg.	neg.	1	allowed
3		pos.	neg.	-1	not allowed
4		neg.	pos.	-1	not allowed

Case 1 and 2 (the inverse conventional and the conventional droop) are characterised by the same sign of both droop factors. This requires k to be 1, which results in an inverter voltage which is near the grid voltage. Only little reactive power is needed to tune the voltage, whereas in case 3 and 4 huge reactive power is needed. Even worse, the inverter power and a huge amount of grid power is dissipated in the line. Therefore case 3 and 4 is not allowed. Following the plots of the inverter voltage U_{inv}, the grid voltage U_{grid} and the voltage drop across the line U_{line} are depicted for all four cases in Table 2 with an injected inverter power of 10 kW. They were computed with the simulation tool *SIMPLORER^{TM}*. A single phase system is modelled assuming a line resistance of 0.5 Ω. This corresponds to about 1 km line length.

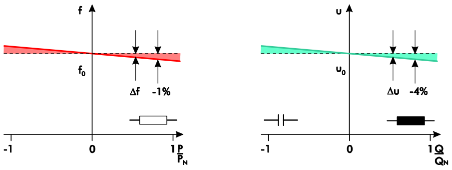


(a) droops with positive p_{droop} and q_{droop}

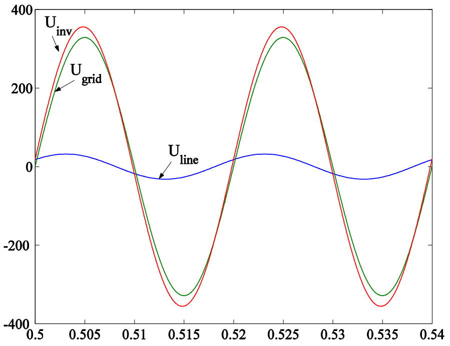


(b) voltages @ 10 kW and 3.3 kVar

Figure 2.1: Case 1: Inverse conventional droops

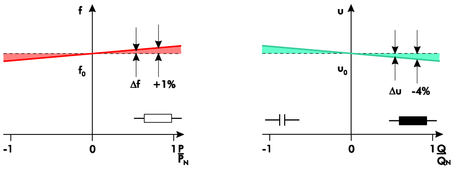


(a) droops with negative p_{droop} and q_{droop}

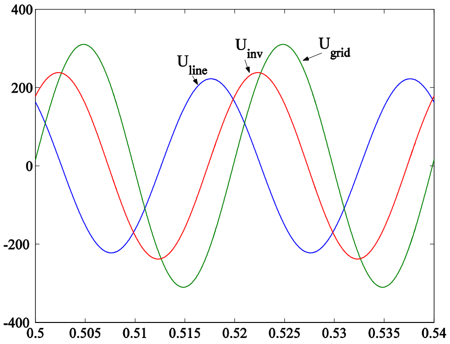


(b) voltages @ 10 kW and -3.3 kVar

Figure 2.2: Case 2: Conventional droops

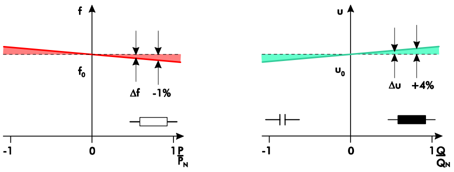


(a) positive p_{droop} and negative q_{droop}

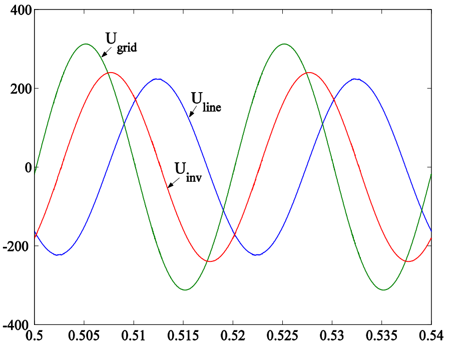


(b) voltages @ 10 kW and 72 kVar

Figure 2.3: Case 3: not allowed



(a) negative p_{droop} and positive q_{droop}



(b) voltages @ 10 kW and -72 kVar

Figure 2.4: Case 4: not allowed

CONCLUSION

It has been shown that the droops, used in the interconnected grid, can be used effectively on the low voltage level due to their "indirect operation". The only boundary condition is the same sign for the frequency as well as for the voltage droop factors. As a consequence of this outcome the control strategy of the conventional grid can be down scaled to the low voltage level without any restrictions. This coherence will support the introduction of DER and RES on the low voltage level and concerns about grid stability and safety can be alleviated.

ACKNOWLEDGEMENT

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REFERENCES

[1] Lynch, J.: *MicroGrid power networks*. Cogeneration & On-Site Power Production, James & James, London, May-June 2004.

[2] Engler, A.: *Control of Parallel Operating Battery Inverters*. 1st PV Hybrid Power Systems Conference, Aix-en-Provence, September 2000.