POWER QUALITY ASPECTS OF DIFFERENT CONTROL SCHEMES OF BACK-TO-BACK CONVERTERS INTERFACING UTILITY-GRID TO MICROGRID

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ABSTRACT

Microgrid is usually connected to the utility-grid and is therefore exposed to common utility power-quality disturbances, which can seriously influence the microgrid operation. A particular area of concern is the large current flow along the interconnecting distribution feeder between the micro- and utility grids during utility voltage sags. Generally, back-to-back converters are used for power flow control and also frequency isolation between the utility and the microgrid. In this paper, the impacts of different control schemes of back-to-back converters on the power quality indices of microgrid are investigated. It is shown that appropriate selection of control strategy can lead to a desired power quality index for the available loads in the microgrid, when back-to-back converters are used to connect microgrid to the utilty-grid.

INTRODUCTION

Distributed Generation (DG) systems, powered by microsources such as fuel cells, photovoltaic cells, and microturbines, have been gaining popularity among the industry and utilities due to their higher operating efficiencies, improved reliabilities, and lower emission levels. A more recent concept is to systematically group a cluster of loads and paralleled DG systems in a common local area to form a microgrid [1]. Being a larger entity, a microgrid is anticipated to have a larger power capacity and more control flexibilities to fulfill system reliability and power-quality requirements, in addition to all inherited advantages of a single DG system. The formed microgrid is usually connected to the utility-grid and is therefore exposed to common utility power-quality disturbances. These power disturbances can seriously influence the microgrid operation where a particular area of concern is the large current flow along the interconnecting distribution feeder between the micro- and utility grids during utility voltage sags, assuming that voltages in the microgrid are well regulated to prevent tripping of sensitive loads. To mitigate the impact of grid disturbances on the microgrid, back-to-back converters can be deliberately used. They can also provide power flow control between utility and microgrid and total frequency isolation between the utility and the microgrid. In this case, voltage or frequency fluctuation in the utility side has no severe impact on the voltage or power in the microgrid side [2]-[4].

In [8] the dynamic performance of a VSC-HVDC system under unbalanced faults in ac systems is investigated. The results show that the system resumes normal operation after fault clearing using different control systems. Transient performances of different control systems are analyzed.
Figure 1 shows an overview of a sample microgrid connected to the utility-grid by a back-to-back converters link. Back-to-back converters nominated as station 1 and station 2 in Figure 1 could have identical structures. A "grid-switch" is foreseen to disconnect the grid from the microgrid.

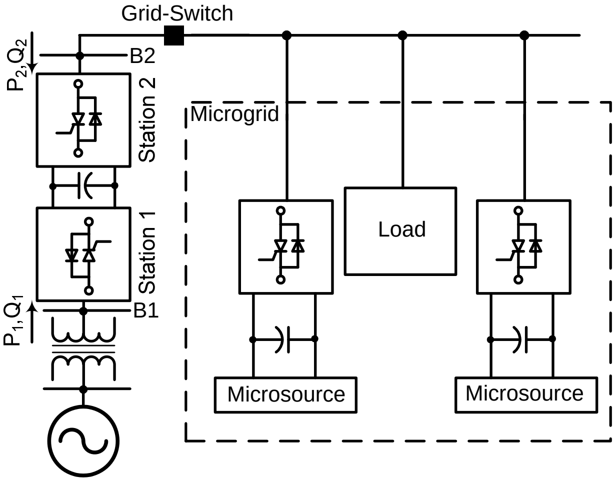

Figure 1: Sample network used for study.

For a safe operation of any sensitive load, it is not desirable to have any sudden changes in the system voltage and frequency. The isolation between the grid and microgrid in emergencies not only ensures safe operation of the microgrid, but also prevents direct impact of microgrid load change or change in DG output voltage on the utility side. In [5] another application of back-to-back converters is introduced; concerned with wind generation. As the wind penetration is increasing, the international standards are oriented to consider the wind turbine systems as classical generation system that should sustain the grid when necessary, for example generate/absorb reactive power. These requirements make possible to foresee that the future standard wind systems will include a back-to-back converter. This would allow the full control on the power injected into the grid. Therefore, a wind generation system has to be able to 'ride through' a severe voltage dip or swell, as well as a frequency disturbance or other occurrences of deteriorated power quality.

In this paper, the impacts of different control schemes of back-to-back converters on the power quality indices are investigated. It is shown that appropriate selection of control strategy can lead to a desired power quality index for the loads present in the microgrid. For example, if sensitive-to-frequency loads are available in the microgrid, it is preferable to select a control strategy for back-to-back converters to stabilize the frequency of the microgrid during the grid disturbances or even when the grid is disconnected. When keeping voltage magnitude within selected limits in the microgrid is of major concern, it is desirable to apply a control strategy to cope with voltage sags and fluctuations.

CONTROL SYSTEM SCHEMES

Figure 2 shows the control system of one of the converters of the back-to-back converters link, including its interface to the main network [6]. The two controllers of the station 1 and station 2 in Figure 1 are independent with no communication between them. Each converter has two degrees of freedom. These are used to control P and Q in one station, and Udc and Q in another station. The control of the AC voltage would be also possible as an alternative to Q. The phase locked loop (PLL) shown in Figure 2 is used to synchronize the converter control with the line voltage and also to compute the transformation angle used in the d-q transformation. The PLL block measures the system frequency and provides the phase synchronous angle Θ for the d-q transformations block. In steady state, sin (Θ) is in phase with the fundamental (positive sequence) of α component and phase A of the point of common coupling voltage (U_{abc}). The active power or the DC voltage is controlled by the control of δ, i.e., the phase displacement angle. The reactive power is controlled by the control of the modulation index (m).

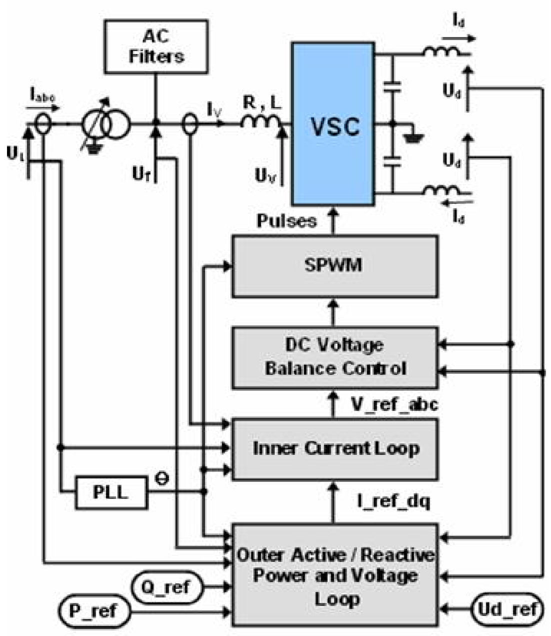

Figure 2: VSC control system block diagram.

The instantaneous real and imaginary power of station1 on the valve side can be expressed in terms of the dq component of the current and the voltage on the valve side. If the reference of the dq-frame is selected such that the quadrature component of the voltage is being very small and negligible then the active and the reactive power are proportional to the d and q component of the current respectively. Accordingly, it is possible to control the active power (or the DC voltage or the DC current) and the reactive power (or the AC bus voltage) by control of the current components, respectively. The active and reactive power and voltage loop contains the outer loop regulators that calculate the reference value of the converter current vector which is the input to the inner current loop. The difference between the DC-side voltages (positive and negative) are controlled to keep the DC side of the three level bridge balanced in steady-state [7].

POWER QUALITY IN MICROGRIDS

Large industries have high electricity consumption and are typically supplied directly from the sub-transmission grid. This results in a very reliable supply to the plant. Moreover, many industrial customers, such as pulp and paper industries, refineries and steel factories, have facilities with on-site generation. The on-site generation has several benefits for the industries as well as the utility grid such as reducing electricity costs and improving the power quality. However, power-quality disturbances can still spread directly from the supplying grid to the industrial installation and vice versa. A back-to-back converters link is capable of transferring the active power from the grid and, at the same time, decreasing the disturbances from the utility grid.

When such a back-to-back converters link supplies the industrial network, the stations can use the AC voltage and frequency controllers to keep the load side AC voltage and frequency constant. In this way power-quality disturbances like voltage dips do not reach the industrial installation. However, due to the low inertia in the industrial network, the control and operation of industrial installations differ considerably from that of large transmission or sub-transmission networks [8]-[9].

POWER QUALITY AND FAULTS

Active power control will play an important role both during grid faults and in normal conditions. During unsymmetrical faults, owing to the appearance of a negative sequence and amplitude drop in the grid voltages, the current magnitude that is delivered by the microgrid to the grid will rise considerably for the same amount of delivered power. Moreover, a negative-sequence current will appear, flowing uncontrollably through the power converter of the distribution system. In this sense, a series converter that is connected at the PCC and controlled as current limiting impedance can be used as a solution to limit the current rising inside the microgrid. With respect to the negative-sequence current flowing through the grid-connected power converter, the implementation of a dual current controller, with one for the positive-sequence current and one for the negative-sequence current, has been discussed, and improved results are noticed when the negative-sequence current is also controlled. It should be noticed that the complexity of the controller is doubled in this case, and an algorithm for detection of both positive and negative-sequence components is necessary. The ripple of the dc-link voltage has influence on the reference currents, leading to non-sinusoidal current injection [10].

SIMULATION RESULTS

In order to test the dynamic responses of the back-to-back converters link, different test cases as Table 1 are studied. Figure 3 shows the results obtained from a minor and a severe perturbation started from the steady-state condition and executed at station 1 and 2 systems, respectively. A three-phase voltage sag is first applied at station 1 bus, B1, then, following the system recovery, a three-phase to ground fault is applied at station 2 bus, B2. The system recovery from the perturbations should be prompt and stable. Figure 3 shows the RMS voltage magnitude of bus B1, active power P1 and reactive power Q1, respectively [7], [11]-[14].

Case 1: Voltage Step on AC System 1

The AC voltage step (-0.1 pu) is applied at t=1.5 s during 0.14 s (7 cycles) at station 1. The results show that the active and reactive power deviation from the pre-disturbance is less than 0.09 pu and 0.2 pu respectively. The recovery time is less than 0.3 s and the steady state is reached before next perturbation initiation.

Case 1: Three-Phase to Ground Fault at Bus B2

The fault is applied at t=2.1 s during 0.12 s (6 cycles) at station 2. During the three-phase fault the transmitted DC power is almost halted and the DC voltage tends to increase since the DC side capacitance is being excessively charged. A special function (DC Voltage Control Override) in the Active Power Control (in station 1) attempts to limit the DC voltage within a fixed range. The system recovers well after the fault, within 0.5 s. The damped oscillations (around 10 Hz) in the reactive power are visible from the figure. Figure 3 is extracted based on the control systems of case1 as Table 1, i.e., the control system of station 1 is assigned to active and reactive power control, while station 2 is responsible for controlling DC voltage and reactive power. Figure 4 shows the same results for case 2, i.e., both stations have active and reactive power control. Comparison of Figures 3 and 4 reveals that the voltage dips during minor and major disturbances are improved, while the active power recovery after the perturbations are not satisfactory. It means the control systems of the stations have a direct impact on the expected power quality. The nature of the load should be considered in selecting the control strategy.

Table 1: Different control systems used for back-to-back converters

Case #	Station 1 Control System	Station 2 Control System	Power Quality Merit
Case 1	active and reactive power	DC-Voltage and Reactive Power	Active Power
Case 2	active and reactive power	active and reactive power	Voltage Sag
Case 3	DC-Voltage and Reactive Power	DC-Voltage and Reactive Power	No Merit

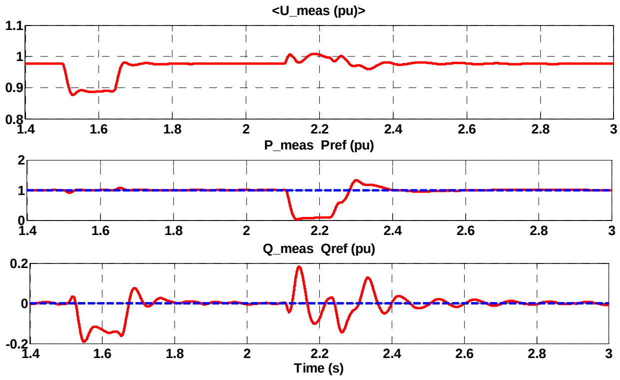

Figure 3: P1, Q1 and voltage of bus B1 in the sample system for a minor and a severe perturbation at t=1.5 s and t=2.1s, control systems as case 1.

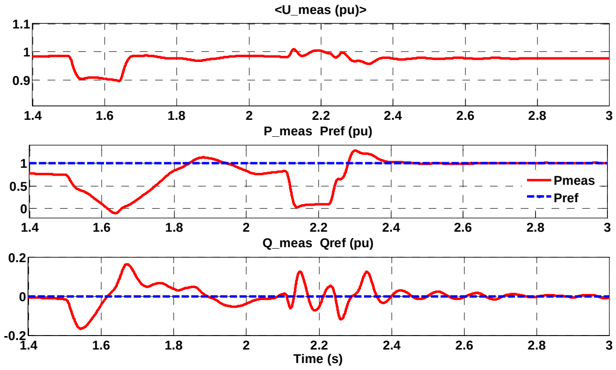

Figure 4: P1, Q1 and voltage of bus B1 in the sample system for a minor and a severe perturbation at t=1.5 s and t=2.1s, control systems as case 2.

The motivation for choosing the control strategy depends on the load dynamics, for example, the processing industries are much more sensitive to voltage drops than to frequency deviations, in this the control schemes with the capability of confronting with voltage dips are preferable, hence, case 1 according to Table 1 is more applicable than case 2.

Figure 5 shows the same results for case3, i.e., both stations use DC-Voltage and Reactive Power control. According to this figure, the voltage is not better than case 2, but relatively improved with respect to case 1. For active power no significant improvement is achieved with respect to the cases 1 and 2. It can be concluded that stabilization of DC voltage at both station does not enhance the active power recovery after major or even minor perturbations.

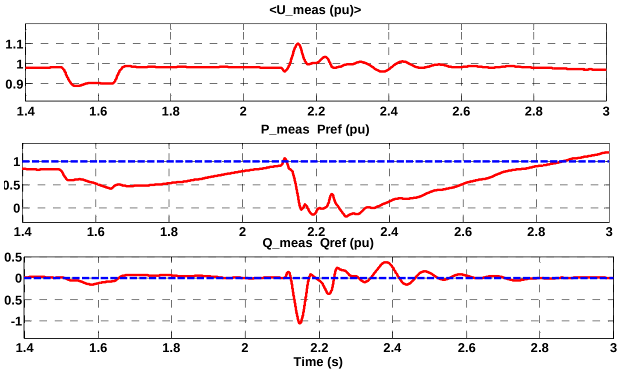

Figure 5: P1, Q1 and voltage of bus B1 in the sample system for a minor and a severe perturbation at t=1.5 s and t=2.1s, control systems as case 3.

CONCLUSION

Power quality problems are issues of priority for owners of industrial plants, grid operators and for the public. The increasing penetration of distributed power generation into the power system leads to a continuous evolution of grid interconnection requirements. In particular, active power control will play an important role both during grid faults and in normal conditions. The aim of this paper is to present two points:

1) The connection of industrial plants and sensitive loads within a microgrid is much improved if the connection to the grid is performed by a back-to-back converters link.

2) The control strategies used for the stations of the back-to-back converters have a direct impact on the power quality of the consumers within the microgrid.

3) Simulation results show that when a back-to-back converters link is applied to an industrial system, if the control system of station 1 is assigned to active and reactive power control, and of station 2 to DC voltage and reactive power control, it can improve the power quality of the industrial plant during voltage disturbances; it could be much improved if both controllers use active and reactive power controllers at the expense of degrading the power flow recovery after removal of the disturbance.

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