DECENTRALISED CONTROLLER FOR FLICKER MITIGATION IN CONVERTER-CONNECTED DG NETWORKS

Piyadanai PACHANAPAN, Adam DÝSKO, Olimpo ANAYA-LARA, Graeme BURT, Kwok L.LO
Institute for Energy and Environment, University of Strathclyde, Glasgow, UK
piyadanai.pachanapan@eee.strath.ac.uk
a.dysko@strath.ac.uk
olimpo.anaya-lara@eee.strath.ac.uk
gburt@strath.ac.uk
k.lo@eee.strath.ac.uk

ABSTRACT

A decentralised controller that allows converter-connected distributed generation (DG) to enhance power quality and overall network performance is presented. To this aim, the controller uses the capabilities of the DG grid-side converter to mitigate flicker and to reduce the requirements for additional compensation and power conditioning devices such as STATCOM, in the medium-voltage network. The case study is based on the IEEE 33-bus network implemented in DIgSILENT PowerFactory.

INTRODUCTION

Voltage flicker in distribution networks can be generated by intermittent DG sources, such as fixed-speed wind turbines, or industrial loads such as arc furnaces. It can be reduced by installing active compensation devices such as STATCOM. However, this solution is costly and increases the harmonics injection [1]. Alternatively, the converter interface in some type of DG sources can also provide fast active voltage control as that of dedicated compensation devices, reducing thus network complexity and costs.

The decentralised controller presented in this work is designed based on voltage controllable areas named “Local Controllable Zones” (LCZs). The size and number of zones depend on the DG network topology, and the number and location of the DG units.

VOLTAGE FLICKER

Voltage flicker originates from the variations in active and reactive power. The relative voltage fluctuation is given by

$$\frac{\Delta V}{V} = \frac{R\Delta P + X\Delta Q}{V^2} \qquad (1)$$

Where ΔP and ΔQ are the variation in the active and reactive power injected to the grid; V is the nominal voltage and R and X are the resistance and reactance of the grid impedance. Since R is usually very small compared to X, ΔV is proportional to Q. Therefore, voltage flicker can be mitigated by reactive power control [1].

Flicker measurement

Flicker is typically measured using a flickermeter. The standard IEC 61000-4-1 provides the functional and design specification for flickermeter intended to indicate the correct flicker perception. The IEC flickermeter was originally based on a 230 V, 60 W incandescent lamp and the architecture can be divided into two parts [2]; 1) simulation of the response of the lamp-eye-brain chain, and 2) Online statistic analysis of the flicker signal and presentation of the flicker indices, P_{st} and P_{lt}. P_{st} is a short term flicker index measured over a period of 10 minutes, and P_{lt} is a long-term index corresponding to a period of 2 hours.

Voltage flicker standard

The IEC 61000-3-7 standard indicates the compatibility levels for flicker in LV and MV systems as $P_{st} \leq 1$ and $P_{lt} \leq 0.8$ respectively. In this work only P_{st} is considered. The normalised flickermeter response (P_{st}=1) versus frequency, and the shape of the flicker are shown in Fig. 1 [3]

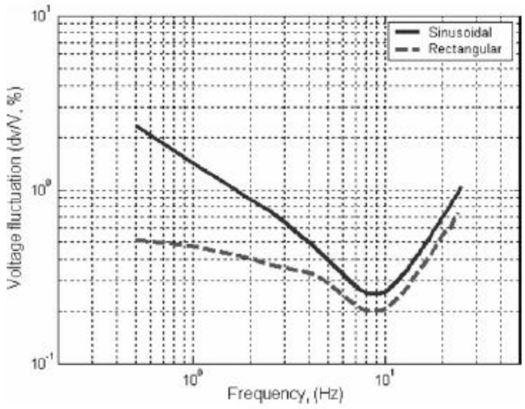

Figure 1. Normalised flickermeter response for voltage variation

CONVERTER CONNECTED DG

Most DG units operate at active power (P) and reactive power (Q) constant (mostly operating at unity power factor). However, some Grid Code now enforce that DG must be able to provide dynamic voltage support and operate at a 0.95 power factor (both, leading and lagging) such as Germany’s code in [4].

The converter-connected DG is modelled as the grid-side voltage source converter (VSC) connected with a DC source and space-vector pulse-width modulation (PWM) is used as the switching technique. The controller is based on the conventional current-mode control technique where P and Q are controlled by controlling the amplitude and phase angle of the line current with respect to the voltage at the point of common coupling (PCC). A phase-lock loop (PLL) is used for measuring the AC network frequency. The line current in the *abc*-frame is transformed into the *dq*-frame. Furthermore, the voltage (V) control loop is added to allow the DG units to provide active voltage control by adjusting their reactive power output. The P and V control structure is shown in Fig. 2.

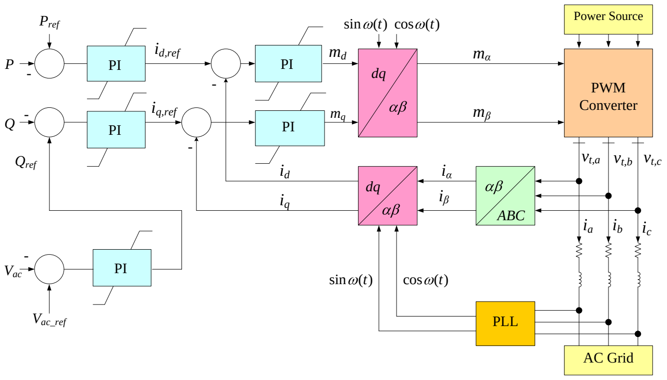

Figure 2. *P-V* control system of grid interfaced VSC

DECENTRALISED VOLTAGE QUALITY CONTROL

The concept of the decentralised control is shown in Fig. 3. The DG network is split into LCZs where a zone consists of DG and other autonomous controllable devices that can provide voltage control to all buses located within that zone. A control algorithm is designed to control the converter-connected DG and controllable devices in a coordinated manner to address short-term voltage issues. The local zone controller has online monitoring capabilities, acquiring the relevant signals from the zone, and other neighbouring zones as required by the control algorithm.

The size and number of LCZs depend on the network topology, and the number and location of DG units. The zone boundary is defined based on the DG voltage control capability, which should be enough to handle voltage changes in all buses within the zone.

The V/Q sensitivity between buses in the network is calculated to identify the LCZs. Additionally, the sensitivity matrix, $[\partial V/\partial Q]$ is the inverse of the matrix $[\partial Q/\partial V]$ which is a part of the Jacobian matrix from the Newton-Raphson power flow calculation. It is found that the elements of $[\partial V/\partial Q]$ reflect the propagation of voltage variations responding to the injection of reactive power at a bus. The zone boundary can be defined from the level of voltage change in response to a reactive power perturbation at the DG bus. All buses within the zone have a voltage fluctuation level above the threshold value (ΔV_{th}) identified by the system designer.

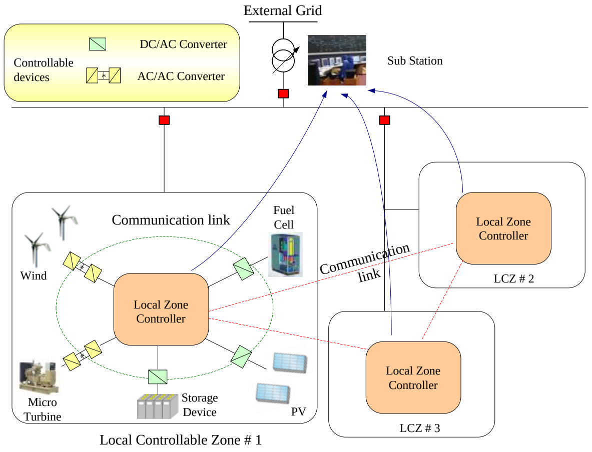

Figure 3. The decentralised control structure in DG network

Voltage flicker mitigation using converter connected DG

Distributed automation control and management based on flicker disturbance mitigation is used across the controllable devices, mainly converter-connected DG, to decrease the level of voltage fluctuation. In addition to maintaining the voltage level at its PCC, assumed as "local bus", each converter-connected DG aims to provide support to 'remote buses' where the flicker source may be located, as shown in Fig 4.

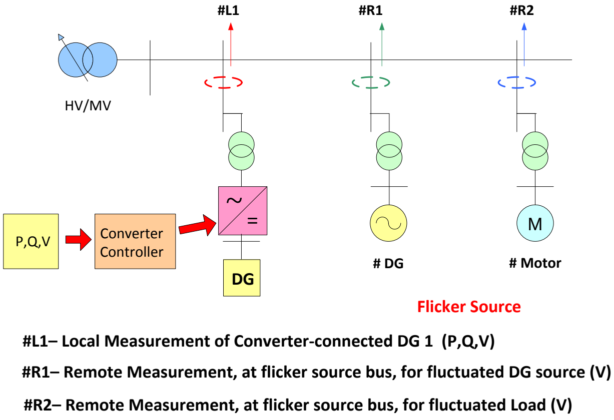

Figure 4. Voltage flicker mitigation using converter-connected DG

TEST SYSTEM

The IEEE 33-bus distribution system is used as the test system [5] (see Fig. 5). For this investigation, two 1-MW DG units are connected to the network. DG 1 is assumed as fixed speed wind generation connected at bus 11 and DG 2 is converter-connected DG connected at bus 7. This converter-connected DG can operate at 0.95 power factor, with a ±0.33 MVar capacity to provide dynamic voltage control.

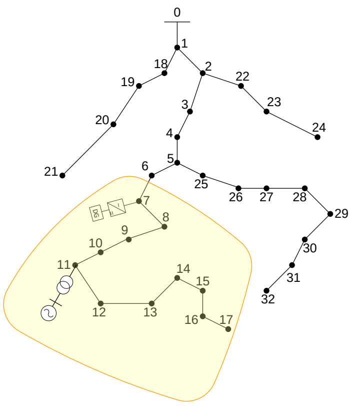

Figure 5. IEEE 33 bus radial distribution system

The LCZ is identified from the voltage sensitivity $\partial V/\partial Q$ between the converter-connected DG bus and all buses across the network. The voltage change due to a 0.33 MVar reactive power injection at bus 7 is shown in Fig. 6. If ΔV_{th} is defined as 0.005 p.u. (meaning that the injection of Q=0.33 MVar from DG unit can mitigate a 0.5% voltage, at least), the LCZ is identified as shown in Fig. 5.

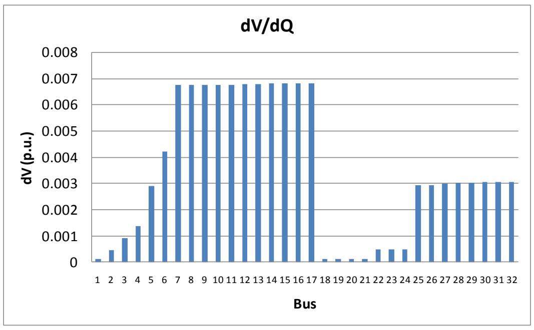

Figure 6. *dV/dQ* from the injection Q=0.33 MVar at bus 7

Cast study

The flicker voltage is generated from the fluctuation of the DG 1 power output at bus 11. The flicker is assumed to be sinusoidal, with a ±1.0 % voltage variation and frequency of 2 Hz. However, from Fig. 1, the statutory limit for a 2-Hz sinusoidal flicker is about 0.8%. The *V-Q* curve of bus 11 in Fig. 7 shows that the voltage change of ±1 % can be mitigated by supplying around ±0.3 MVar, so the Q capacity of DG 2 is sufficient to mitigate the voltage flicker at bus 11. Three scenarios are presented and discussed to demonstrate the performance of the proposed controller:

Case 1**:** using converter-connected DG to control the flicker at a remote bus (bus 11)

Case 2**:** using converter-connected DG to control the flicker at a local bus (bus 7)

Case 3**:** using only a STATCOM (0.3 MVar) at the flicker source bus 11

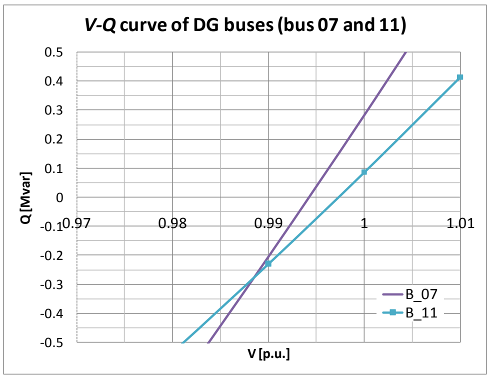

Figure 7. *V-Q* curve at flicker source (bus 11)

SIMULATION AND RESULTS

The case study is conducted using RMS transient simulations in DIgSILENT *PowerFactory*. The voltage flicker waveforms at buses 7, 11, 17 and 24, for the three scenarios, are shown in Fig. 8(a) to 8(c). The reactive power supplied by the converter-connected DG and the STATCOM is shown in Fig. 8(d). Furthermore, the P_{st} of 10 minute-flicker waveform is calculated using the IEC flicker measurement simulator (sampling rate 2 kHz), called FlickerSim [6], based on MATLAB software. The P_{st} of essential buses in difference scenarios is presented in Table 1, for the three scenarios under study.

Table 1: Short-term flicker index, P_{st}, for the three scenarios.

Bus	P_{st} (Short term flicker index)			
	No compensation	case 1	case 2	case 3
6	0.3466	0.1656	0.0709	0.0771
7	0.6116	0.2594	0.1659	0.1707
11	1.0325	0.4516	0.5870	0.3640
17	1.0325	0.4516	0.5870	0.3640
24	0.0836	0.0372	0.0383	0.0385
25	0.3156	0.1291	0.1145	0.1159

The results show that the STATCOM provides the finest voltage flicker mitigation (e.g. P_{st} is reduced from 1.035 to 0.364 at flicker source bus 11). If converter-connected DG operating with a 0.95 power factor within the same zone, is used to mitigate the flicker, the P_{st} at bus 11 can be reduce by about 0.5.

Using a converter-connected DG unit to control the flicker at remote bus proved to be more effective than using local bus control at the flicker source. However, the remote bus control causes higher voltage fluctuation at the DG bus due the line drop compensation between DG bus and flicker source. Moreover, the remote control requires of suitable communication links to monitor the voltage at the remote bus. Also, if the voltage sensitivity between the converter-connected DG and the flicker source bus is high, then local bus control of the DG unit should be sufficient to mitigate the voltage flicker.

Fig. 8(c) shows that voltage flicker mitigation by using either a STATCOM or converter-connected DG is effective for buses within the same LCZ. It was also found that the flicker mitigation in buses outside the zone is not significant. By way of example, the P_{st} of bus 17, located in LCZ, can be mitigated by about 0.5-0.7. On the other hand, the P_{st} of bus 24, which is outside the zone can only reduced by about 0.05. This is because the voltage sensitivity between the buses outside the zone and the flicker source is small.

From Fig. 8(d), it can be seen that the *P-V* control effectively allows the DG unit to provide reactive power compensation and dynamic voltage control. Furthermore, the *Q* supplied by DG 2 in case of using remote control is higher than using local control because *Q* is compensated via the line reactance between DG and flicker source.

CONCLUSION

Converter-connected DG with voltage controllability can be effectively used to decrease the level of flicker within a LCZ, with similar results as those obtained when a STATCOM is connected at the bus where the flicker is originating. Thus, additional local compensation equipment may not be required, hence improving network reliability and reducing costs. Moreover, the work presented demonstrates that DG converter interfaces are better utilised when they are used to control the power quality not only at the point of connection, but, across the whole LCZ. Flicker mitigation using of converter-connected DG is very effective without communication system requirements, when it is connected near the flicker source, for example a mixed DG system comprising fixed-speed wind generation, and either PV or fuel cells within the same LCZ.

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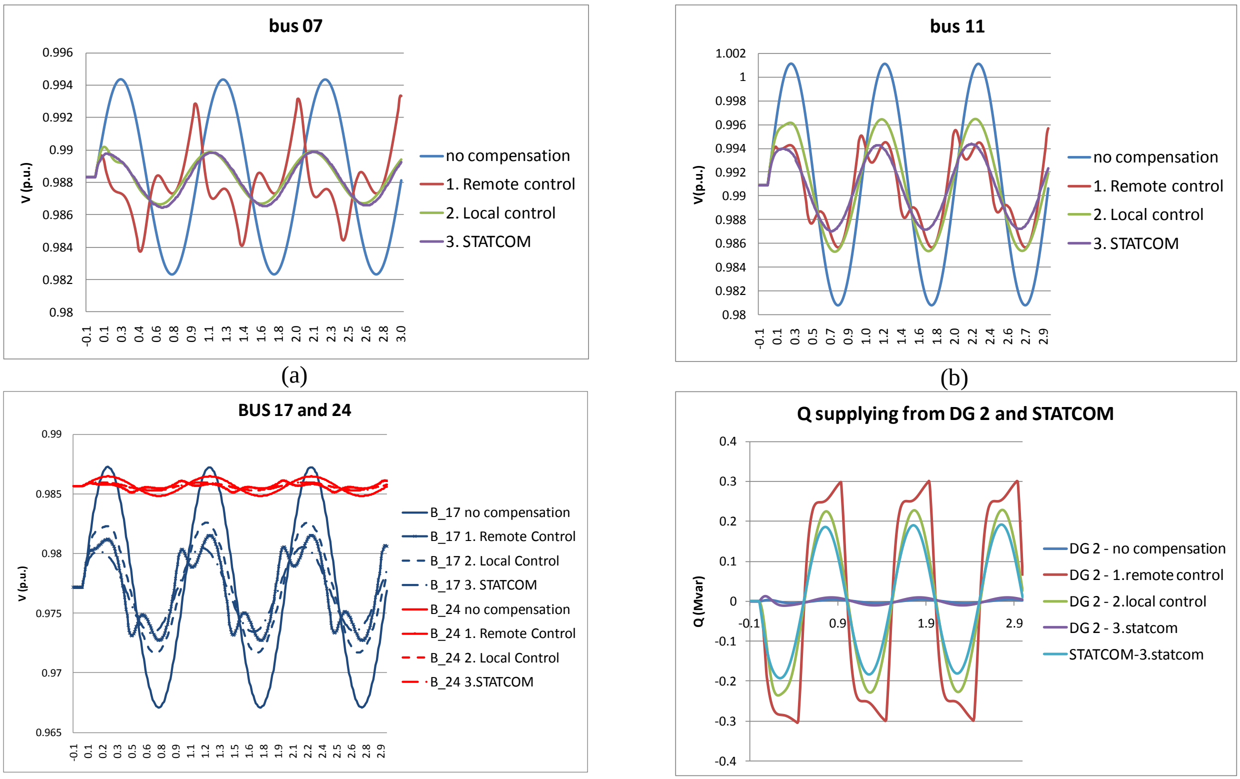

(a) (b)

(c) (d)

Figure 8. Voltage flicker waveforms and *Q* supply in different scenarios