Grid harmonic suppression / torque ripple suppression

Contents

1 Intent

Grid-side converters DW2020 can be used in conjunction with renewable power sources, front-end rectifiers of electrical drives, energy-storage facilities in microgrids, *prosumer* installations and similar. For a grid-side converters, it is of uttermost importance to suppress line-frequency harmonics and associated oscillations. Thus, an upgrade of DW2020 controls that enables line-harmonic suppression would give competitive advantage to the “2020” family of power converters.

Motor-control converters DM2020 incorporate digital current controller with the best known bandwidth-to-switching frequency ratio. Yet, with most recent motors with increased torque-to-weight ratio and with their non-sinusoidal back-EMF, high speed operation often pushes the back-EMF harmonics well beyond the closed loop bandwidth. In such cases, the loop cannot suppress the consequential current harmonics that give rise to the torque ripple. Therefore, it is of interest to enhance DM2020 controller, suppress harmonics and eliminate the torque-ripple.

2 Harmonic suppression in grid-side converters

Grid-side converters connect to the ac network through an LCL output filter, suited to suppress the PWM ripple from entering into the grid. Typical [p.u.] values of the filter components are L = 0.05 and C = 0.05. When turning these numbers into impedances and when considering low-order line harmonics from 5th up to 19th, the LCL output filter along with grid impedance can be envisaged as an equivalent series reactance X, connected between the converter voltage U_C and the grid no-load voltage U_0.

2.1 Harmonic injection limits

Recommended practice for the grid-side converters such as DW2020 envisages limits for the injected low-order line harmonics that range from 4% (5th) down to 0.6% (23rd). Harmful effects of line current harmonics include interactions with inter-harmonics and increased likelihood of interference between grid-converters, their LCL filters and other loads, that could lead to untamed resonance and instability above the line frequency. At the same time, emphasized line harmonics worsen the situation with subsynchronous oscillations. More information can be found in

IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems,
IEEE Standard 519−2014 (Revision of IEEE Standard 519−1992), Jun. 2014, pp. 1–29.

2.2 Harmonics caused by the lockout time

Converter voltage U_C is generated through the PWM action of the power switches, and its main component is the line-frequency ac-voltage with an amplitude and phase that suites the needs of the desired power injection. In addition, there is considerable voltage component at the PWM switching frequency, which does not penetrate into the grid due to the filtering action of the LCL. Due to inverter imperfections such as the lockout time, there are also other parasitic voltage components. Imperfect compensation of the lockout time and residual dead-time (lockout-time) errors give rise to low order line harmonics (5th, 7th, 11th, 13th, 17th, 19th...). Divided by series reactance X, such voltage harmonics give rise to current harmonics. As an example, for the lockout-time (dead-time) error of 2μs and with f_{PWM} = 16 kHz, the fifth harmonic voltage component reaches 0.012 [p.u.]. With X = 0.1, the consequential 5th harmonic component of the current reaches significant level of 2.4%. Similar considerations can be done for other harmonics.

2.3 Line harmonics

With elevated number of loads that comprise diode rectifiers or other power electronics converters, the load currents get increasingly non-sinusoidal, and this gives a rise to harmonic distortions of line voltages. Whenever the grid no-load voltage U_0 comprises low frequency line harmonics, each of these causes corresponding harmonic currents, inversely proportional to a relatively low X. The amount of 5th-7th harmonic reaches 5% and 3%, which provokes considerable distortion.

2.4 Suppression

In order to suppress harmonic injection into the grid, it is of interest to

- provide the means of accurate and quick detection of the amplitude and phase of line current harmonics, suitable for the use in a closed-loop harmonic-suppression system;
- provide the through-converter transfer function for selected harmonics in order to establish the link between the voltage inputs and the line-current output at specific frequency;
- provide the controller structure for suppression of selected harmonicsWith elevated number of loads that comprise diode rectifiers or other power electronics converters; and
- provide for a robust parameter setting that secures resilience of the harmonic suppressor in the presence of perpetual changes of ac-grid topology and parameters.

Preliminary considerations of TI DSP 28377D platform shows that the above functions are feasible.

3 Harmonic suppression in motor-control converters

The stator current in converter-fed ac motors depends on the voltage difference between the back-electromotive force and the converter-supplied voltage, and it is inversely proportional to the stator impedance. Prevailing part of the stator impedance (at relevant frequencies) is the stator reactance X_S. In synchronous motors with surface-mounted magnets, the stator inductance is very low, and the relative value of X_S can be far below 0.05. Thus, the presence of voltage harmonics of just a fraction of one percent can give a rise to significant harmonic currents.

3.1 Torque ripple

In conjunction with the motor flux, current harmonics generate the torque ripple, the frequency of which is the multiple of the rotor speed. Therefore, the frequency of torque ripple components sweeps through the range of frequencies as the motor accelerates and brakes. Soon enough, the torque oscillations excite mechanical resonance noise, and they contribute to noise, losses, ware and overall performance.

3.2 Back-EMF harmonics

High flux-density and high torque-density motors usually comprise back-EMF rich with low order harmonics. In cases with reduced number of slots, with fractional-slot windings and with flux-switching machines, low order harmonics from the 5th up to the 19th dwell around 7-10% while some of them reach even larger values. In conjunction with a low X_S, the amount of stator current harmonics is considerable, in some cases it reaches the rated current. These amounts of harmonics cause significant torque ripple that contributes to audible noise, vibrations, ware and speed/position errors. With rotor variable speed, the frequency of said harmonics also changes. Due continuous nature of such changes, the torque ripple can coincide with resonance modes of mechanical subsystem, thus creating additional problems.

3.3 Lock-out time harmonics

Motor-supply converter uses PWM to generate the stator voltage. Inverter imperfections such as the lockout time create parasitic voltage components, the most salient of which are low order harmonics of the fundamental frequency (5th, 7th, 11th, 13th, 17th, 19th...). The ratio between these harmonics and the stator reactance X_S defines the consequential current harmonics. Typically, the impact of dead-time (lock-out time) on stator current is lower than the impact of back-EMF harmonics. It is more emphasized with larger lockout-times and higher switching frequency.

3.4 Suppression

In order to suppress harmonic injection into the grid, it is necessary to resolve the problems listed in Section 2.4. With grid-side inverters, the fundamental frequency is equal to the frequency of the ac grid (50 Hz or 60 Hz). In motor-control applications, the fundamental frequency is variable, and the relevant harmonics of the stator current as well as consequential torque ripple all have variable frequency, proportional to the rotor speed. Preliminary considerations of TI DSP 28377D platform shows that the above functions are feasible.

4 Follow-up

- Getting a brief overview of the required computation and storage resources in order to verify that the DSP units planned for the new platform could do the job.
- Analyze whether envisaged signal acquisition requires particular analog pre-filters.
- Update the new-DSP-platform design accordingly.
- Develop simulation model(s), control concept and parameter setting
- Verify the harmonic-suppression by means of computer simulations
- Practical implementation and laboratory testing.