Current Sensing in Advanced Power Electronics Applications

The progress in the development of power electronics applications such as advanced drives and regenerative electrical conversion needs new hardware components like current measuring transducers with advanced features. LEM provides appropriate solutions for current measurement in such applications. They feature small size (only limited by requirement of the standards for isolation distances), and low output voltage drift for an outstanding accuracy across the working temperature range. **Jürgen Koß, Sales and Marketing Manager Industrial Transducers, LEM, Germany**

Due to human nature and for economical reasons, there has always been a quest to be better and be more efficient in order to facilitate our life, our work, or our processes. This leads to general requirements of technical systems being cost-effective and, at the same time, highly reliable and available (high quality). Nowadays, being aware of mankind's influence on the environment, there is a strong need for the sustainable use of our limited resources in the generation of electrical energy. To enable power electronic applications with enhanced performance, current measurement transducers have always been designed to be state-of-the-art. As a response to this higher market demand, LEM has developed a new series of current transducers (CAS, CASR, CKSR) with an improved performance (Figure 1). Additionally, another series of current transducers (CT series) will be presented for use in advanced power electronics for photovoltaic applications.

Figure 1: LEM current transducers for use in advanced power electronics applications

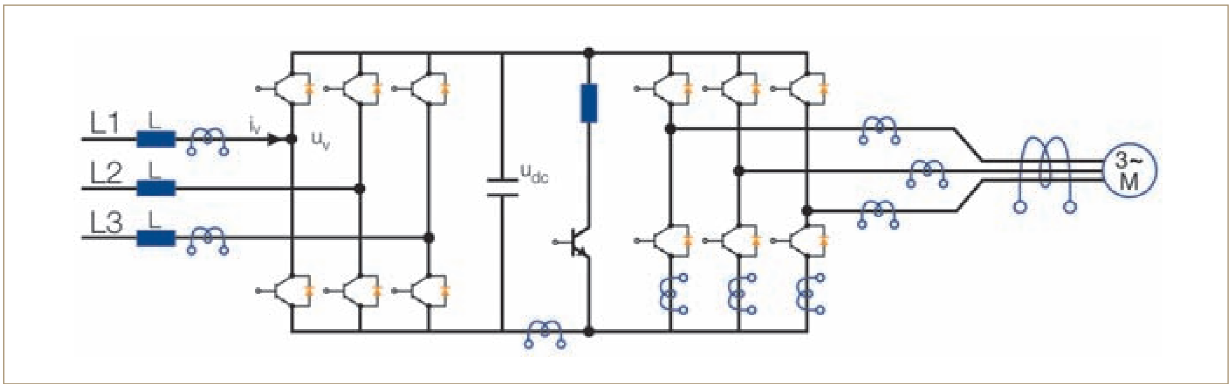
Current sensing in high-performance electrical drives

Having in mind that the vast majority of the electrical energy for industrial use is being consumed by electrical drives, everybody understands the need for a constant progress in the design of highly efficient and high-performance drives. At the same time, these drives should optimise processes, thus leading to an overall cost reduction.

High-performance drives are the so-called servo drives. Their main characteristics can be described by high dynamics with respect to the rotational speed (from 0 up to approximately 10,000RPM) and also a huge torque (in particular the starting torque at 0RPM). There has been a great progress in the evolution of the servo drives consisting of both the motors (induction motors) and the feeding inverters (variable speed drives). This progress has been made possible by improvements in every aspect of the involved components (hardware and software).

Nowadays, the inverter's task is not only

Figure 2: Block diagram of a drive's power electronics with locations for current measurement



to provide the motor with the required variable voltages, frequencies (for the speed) and the currents (for the torque). It also now has superior functions for the motion and process control as well as communications capabilities (several bus-standards are available). In order to fulfill these tasks, several sensors in the drive are necessary. One of these is the current transducer.

In particular, the requirements for the current sensing devices in these inverters today are higher rated currents in smaller packages whilst, at the same time, higher isolation capabilities, a higher accuracy for a wider operating temperature range and, in general, a smarter behaviour in a rugged environment (common-mode behaviour, noise) as an answer to the latest development of faster switching power devices. A nice-to-have feature could be an integrated differential measurement. The answer to these requests is LEM's latest development comprising three series of transducers (CAS, CASR, CKSR) with each four current ratings from 6 to 50A (6, 15, 25 and 50ARMS). The possibilities of current measurement are shown in Figure 2.

Depending on the location, the currents are measured in the inverter. The transducer offers certain functions according to its capabilities:

- Protection of the drive - herewith, the maximum current should be limited in order to not destroy the expensive power devices (e.g. IGBTs). Here, it is crucial that the current transducer is very fast, i.e. it has a very short response time. Closed-Loop transducers like LEM's classical Hall-effect based transducers as well as the Fluxgate based new series CAS, CASR, and CKSR offer this feature (response time at 90% is 300ns). It must also withstand much higher currents for a short time than given by the rated current.
- Protection of the operator - failure currents have to be detected in order to save the operator's life. Here, it is essential that the transducer is able to measure very low currents with a sufficient accuracy.
- Control of the motor - in modern variable speed drives, the induction motor has been modelled in such a way that it is part of the overall control-loop. Common today is a cascaded control loop with torque, speed, motion, and process control (see Figure 3).

These drives have to work properly in different environments, namely different operating temperatures. The influence of the temperature on the drive's control must be minimised. Therefore, a very low temperature drift is essential. Thanks to the Fluxgate technology used in LEM's latest development (CAS, CASR, CKSR), the temperature drift of the transducer's offset is up to four times lower compared to the previous series (LTS, LTSR).

As can be seen in Figure 3, any deviation in the measurement of the current leads to a response of the control circuit – intentionally or by unwanted effects like noise, especially when we look at modern digital controllers with a higher resolution (12bit ADC). The equations 1 and 2 compare the resolution of 8bit ADC and 12bit ADC for the output voltage range of 2.5V biased to the reference voltage of the same level in 5V controllers:

8bit => 28 = 256 steps => 2,5V / 256 = 9,76mV/step resolution (1)

12 bit => 212 = 4096 steps => 2,5V / 4096 = 0,61mV/step resolution (2)

LEM's series LTS has an output noise level of 10mVpp. In an 8bit world, the noise has no influence on the control of the drive. Looking at 12bit shows that the noise level easily captures the lowest 4bits, leading to a reaction of the controller that switches the power semiconductors at the output to control the motor. The result is an unwanted torque effect in particular applications: a shivering of the motor's shaft at zero speed. The latest current transducer generation drastically lowers the noise level, so that the described effects could be easily masked or filtered (for low current ratings transducers), or are even not existing (CASR 25-NP: 0.4mVpp noise) in the 12bit world.

Photovoltaic inverters with enhanced performance

Sustainable (or green) electrical energy generation is one of the keywords today. Besides some niche applications, two main streams have been experiencing huge development in recent years until today: The electrical energy generation by windmills, and by photovoltaics. The latter has recently become the fastest growing market in the world. The interesting aspect of photovoltaics is that every suitable property can be a potential electrical energy source. This decentralised energy generation causes problems, especially due to the fact that the mains grid provides a sinusoidal AC voltage and current while the solar panel generates DC voltages and currents. Inverters are needed to adapt this DC world to the AC world of the grid.

There is a trend towards increasing the power of the inverters while, at the same time, the specific cost (EUR/kW) needs to be lowered. Thus, they are becoming increasingly sophisticated. Furthermore, additional features and capabilities such as diagnostics are being added. The multi-string technology as one of the latest development steps allows the connection of several strings to one inverter, and features a separate MPPT (maximum power point tracking) for each string. This ensures maximum energy yield.

A must in all design topologies is the detection of electrical failures that could harm human life during operation (leakage and isolation errors). In such cases, the operation must be switched off safely according to the standards that vary from country to country.

Although several topologies of the inverter design are on the market, two fundamental design topologies are common when connecting the solar panels to the grid - inverters with a (high-frequency) transformer, and inverters without any transformer.

As transformers provide inherent protection against DC injection into the

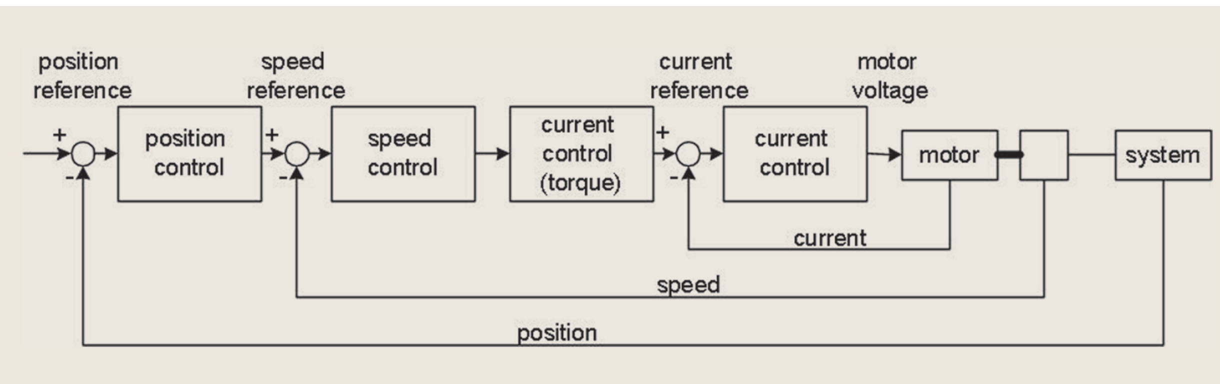


Figure 3: Design of a drive's controller

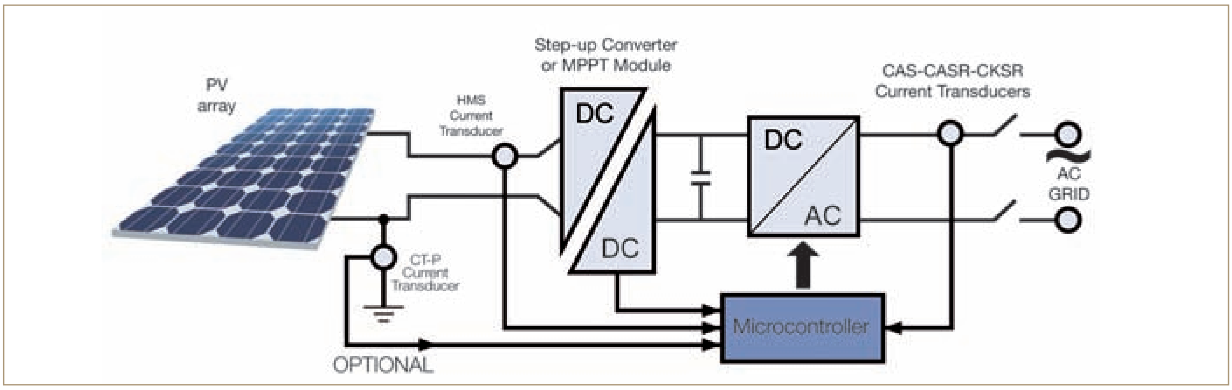


Figure 4: Possibilities to measure the current with transducers in a transformer-less PV inverter

grid, the inverters without transformer need additional electronics in order to limit the DC injection to the lowest allowable limit (also different from country to country due to their regulations). However, the transformer-less designs are electrically more efficient, as the transformer counts for approximately 2% of peak efficiency. In all types of inverters, it is really important to measure the current by means of isolated current transducers. The non-intrusive measurement helps to improve the efficiency and to protect the system.

There are several functions in the chain from the energy generation at the solar panels to the feed-in into the grid, for which LEM offers transducers for current measurement: Inverter-based for the measurement of the single strings (daisy chain of solar panels), for MPPT, for the control of the power devices in the inverter, for earth leakage protection, and the monitoring of solar power plants. Figure 4 shows the different locations for a current measurement.

To monitor and control the MPPT, a current transducer can be used at the DC input of the inverter. As the expected variations of the current changes are slow, LEM provides cost-effective O/L transducers like the HXS or HMS series for measurement at this point. Another important issue is to measure potentially dangerous leakage currents to the ground of the solar panels. As these currents are really low, LEM has offered a special Fluxgate based transducer series called CT series. This series consists of three different types for currents ratings of 100, 200, and 400mA. A special type has two primary jumpers built-in and features an additional jumper for test purposes.

Then, there is the inverter's output with the current flowing into the grid. As this output needs to be synchronised when switched onto the grid, it needs a special control. Also, the current has to be sinusoidal, i.e. the electronics of the inverter have to 'shape' the AC current (fed as DC current from the solar panels) in such a way that the least possible harmonics are being generated. In order to react fast to certain changes on the grid side of the inverter, fast transducers like LEM's new series CAS, CASR, and CKSR are the best choice. Another argument for application of this transducers in solar inverters is that the offset and, in particular, the offset drift is much lower compared to established series. This avoids a complex control algorithm to compensate for effects due to temperature drifts. This lowers the DC part that has been generated by the previous transducers' offset voltage at the output fed into the grid.