SIEMENS

Dynamic Gate Controller (DGC) - A New IGBT Gate Unit for High Current / High Voltage IGBT Modules

1 Introduction

The “Dynamic Gate Controller” (DGC) represents the forth generation of intelligent IGBT driver concepts. The DGC is especially designed to drive and to protect high-power IGBTs as well as to simplify the construction of complete IGBT power stages.

The DGC concept is suitable for applications characterised by the following criteria:

- A perfect protection of the IGBTs with very short delay and switching times
- High PWM carrier frequencies at minimised dynamic power losses of the IGBT
- Low EMI/RFI emissions at a high switching speed (high dv/dt and di/dt slopes)
- A perfect driver and protection circuit for high-voltage IGBTs (V_{ces} > 1600 V)

In contrast to high-power inverters using a SCR or GTO as power switch, IGBT inverters are mainly meant to work at higher PWM frequencies. To operate the power stage at high PWM frequencies, the IGBT has to be switched as fast as possible to reduce the overall power loss and to increase the efficiency of the system. Especially as far as high-power inverters are concerned, high PWM frequencies cannot easily be realised because of the large mechanical set-up and the resulting stray inductance of the wiring. This stray-inductance limits the switching speed of the IGBT due to several well-known effects. Nevertheless, to increase the PWM frequency, snubber networks which are connected to the IGBTs should reduce the max. collector voltage and should keep the dv/dt and di/dt slopes within an acceptable value. In IGBT inverters those snubber networks show only disadvantages. They generate power losses even in no-load operation of the inverter and the snubber has to be mounted on a heatsink. The construction of the power stage becomes more expensive and the snubbers enlarge the total mechanical set-up. Furthermore the snubber components themselves are quite expensive.

To make high-power IGBT inverters competitive to SCR and GTO inverters one has to:

- simplify the mechanical construction, leave out all components which are not necessary to achieve the basic function.
- take full advantage of the current and voltage capability of the IGBTs. This is important in order to compensate the higher component prices for IGBTs as compared to SCRs or GTOs.

In spite of using state-of-the-art power semiconductors, today’s new high-power IGBT inverters show only slight improvements concerning working frequency, efficiency and costs compared to standard SCR- or GTO inverters.

The basic ideas of the DGC are:

- to take full advantage of fast switching IGBT chips in high-power applications.
- to use the “intelligence” of the DGC to get rid of all snubber networks which have so far been necessary to ensure a secure operation of the IGBT.

The use of the DGC in high-power IGBT inverters makes it possible to realise a power stage consisting of only 5 different components:

1. The IGBT modules
2. The Dynamic Gate Controller
3. The power capacitors
4. The low inductive interconnection
5. The heatsink

The DGC fully controls the dynamic parameters of the IGBTs such as dv/dt and di/dt slopes, delay times and diode reverse recovery. All the parameters are independent of each other and are controlled in such a way that the predetermined values which are programmed by the user of the DGC will be achieved under all load conditions either in no-load operation or in full-load respectively over-load/short-circuit operation.

2 General Description

The block diagram **Figure 1** shows the basic set-up of the DGC. The test circuit for all measurements is shown in **Figure 2**. The DGC test circuit was build up as a standard chopper configuration. The high-side IGBT was blocked by a negative gate voltage and the build in diode was used as free-wheeling diode to get the real reverse recovery behaviour. The DGC was connected to the Kelvin collector, the Kelvin emitter, the main emitter and to the gate terminal of the FZ800R16KF1 IGBT module which was used as chopper IGBT.

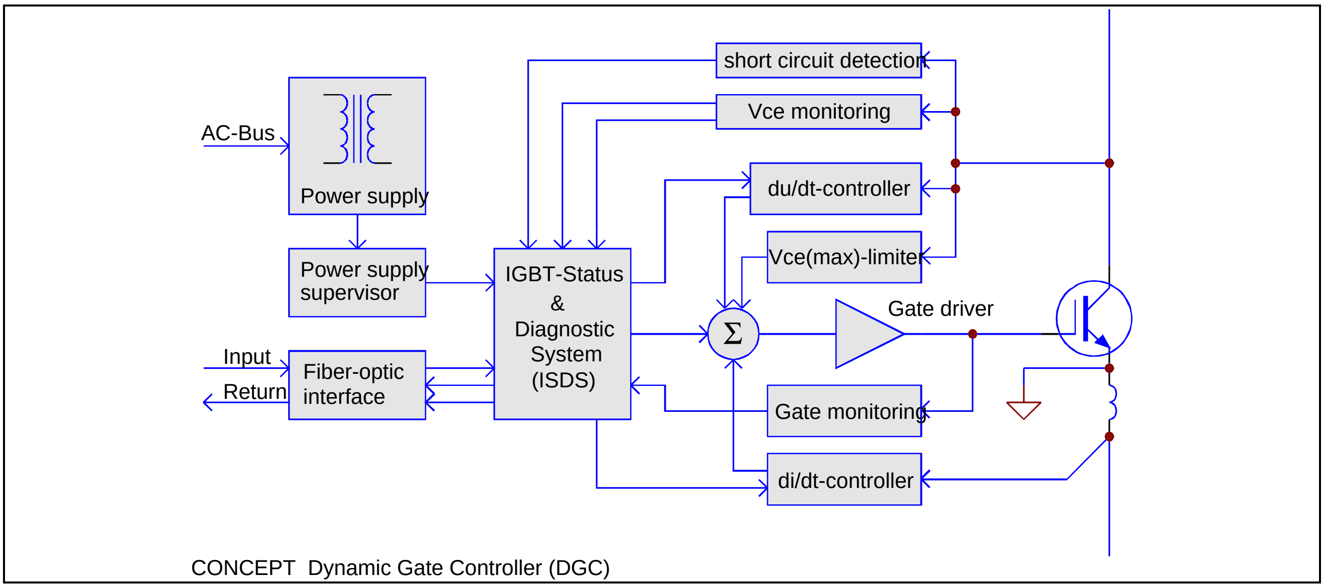

Figure 1
Block Diagram of the DGC

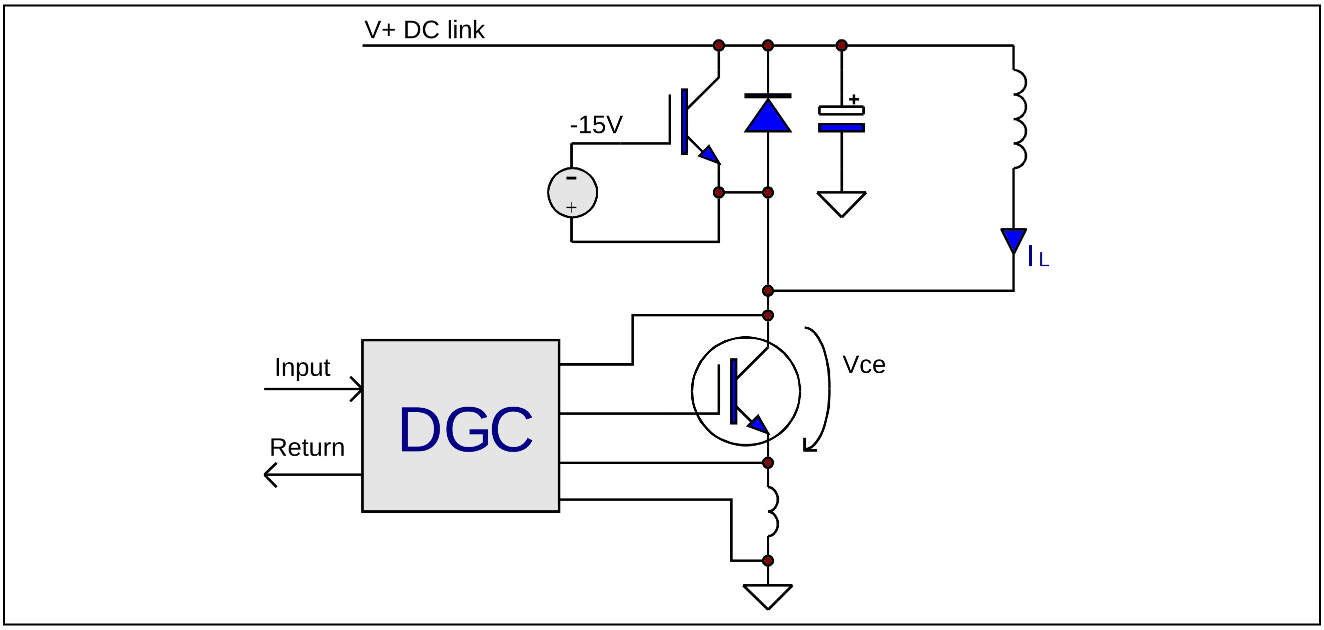

Figure 2
DGC Test Circuit

2.1 Control Inputs

The control inputs consist of a standard fiber optic transceiver and receiver. In normal operation (e.g. inverter power stage) the IGBT is turned on as long as light is turned on. For other applications like crow-bar or DC-link voltage limiter (security relevant applications) “light = on” indicates that the IGBT is turned off. If the supply voltage to the system controller fails, the light signal will disappear and the IGBT will turn on.

2.2 Gate Driver

The driver output stage of the DGC is able to deliver ± 15 A peak gate current together with ± 15 V gate voltage. Due to the modular concept of the DGC the output power can easily be adapted to meet the requirements of future high-power IGBT modules.

The switching performance of the IGBT (as well as the gate currents) are no longer determined by gate resistors which have so far been used in standard straightforward drivers.

In order to operate the IGBT in the desired safe operating area the dynamic turn-on and turn-off controller determines the necessary gate current.

2.3 Dynamic Turn-off Control

To minimise the turn-off power loss of a semiconductor the turn-off transition time has to be as short as possible. Therefore an ideal power switch must turn-off in an infinite short time. But unfortunately this cannot be put into practice with real semiconductors. A lot of parasitic effects limit the possible switching speed:

- High gate capacitances have to be charged and discharged. This results in high peak gate currents which can be handled by a powerful gate driver.
- Additional capacitive currents due to the MILLER-effect of the power chip can dramatically influence its switching performance.
- Stray-inductances of the mechanical set-up and the power module itself create overvoltage spikes during turn-off. To keep these voltage spikes within a certain limit under all working conditions is one of the basic problems in high-power IGBT inverters.
- Turn-on delay time of the free wheeling diode leads to high V_{FR} values, especially with very high di/dt slopes.
- The dv/dt of the motor supply voltage is limited by the windings of the motor. No partial discharge should occur under all working conditions from overload down to no-load operation.
- Electro-magnetic interferences

For standard driver concepts using discrete gate resistors to limit the di/dt and dv/dt slopes it is not possible to operate the IGBT with the optimum switching speed for all load conditions. The gate resistors have to be chosen in such a way that the IGBT stays in the SOA under worst case conditions, normally dedicated to a short-circuit turn-off. The switching characteristic then depends on the load condition and is no longer ideal for nominal or no-load condition.

Using the DGC all dynamic parameters like:

- maximum gate current
- turn-off d*v*/d*t* of the IGBT
- di_F/d*t* of the free-wheeling diode
- maximum IGBT collector voltage

can now be adjusted almost independently of each other and are controlled in such a way that they are independent of the load current. That means that the IGBT works under all load conditions from no-load to overcurrent/short-circuit turn-off with the same d*i*/d*t* and d*v*/d*t* slopes which are predetermined by the manufacturer of the inverter.

Figure 3 shows the turn-off behaviour of a 1600 V IGBT carrying a small load current and **Figure 4** shows the overcurrent turn-off of the same power stage.

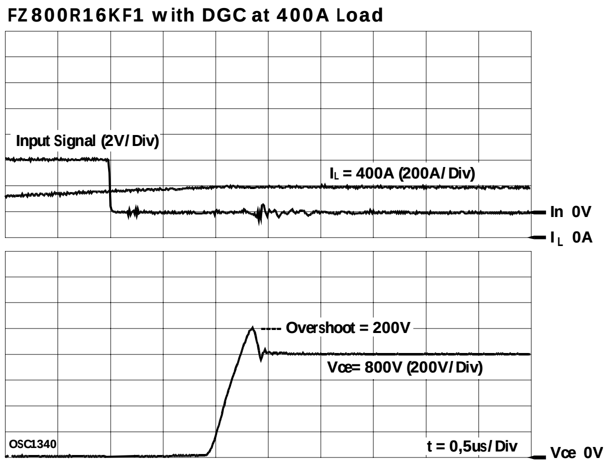

Figure 3
Turn-off Behaviour (low Collector Current)

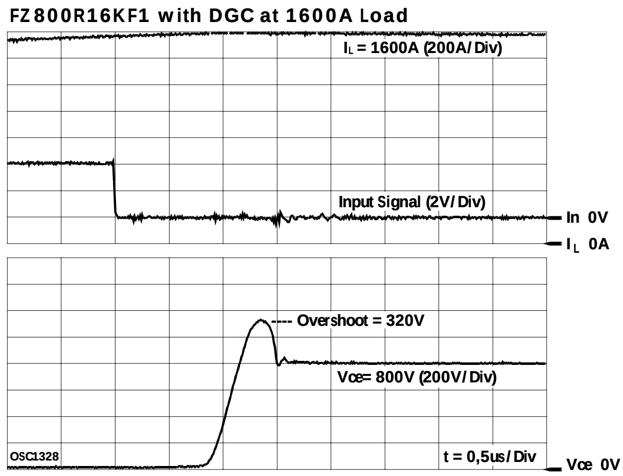

Figure 4
Turn-off Behaviour (Overcurrent)

As depicted, the d*v*/d*t* and d*i*/d*t* slopes are almost the same. So we can for the first time control the dynamic parameters of the IGBT and make them independent of the load current and DC-bus voltage.

2.4 Dynamic Turn-on Control

The DGC controls not only the turn-off but also the turn-on parameters of an IGBT. Apart from the above mentioned problems of gate capacitance, MILLER effect and stray-inductance, another power chip influences the turn-on behaviour of an IGBT: the free-wheeling diode. The reverse recovery characteristic of this device limits the turn-on speed of the IGBT. Especially fast switching high voltage diodes (V_{RRM} > 1600 V) show a worse reverse recovery behaviour than those diodes with a lower V_{RRM}. Higher recovery currents and a fast (snappy) turn-off of the diode lead to high dv/dt ratings and increase the EFI/RFI emission.

The DGC will now control and limit the:

- -di_F/dt of the free wheeling diode
- the turn-on dv/dt of the IGBT

and therefore enables the direct control of the reverse recovery behaviour of the free wheeling diode.

2.5 Electromagnetic / Radio Frequency Emissions

The dynamic turn-on and turn-off control of the DGC dramatically reduces the EMI/RFI emissions of a power stage due to the continuous control of the voltage and current slopes. The dimensions of filter networks can be reduced and the power stages get more cost efficient. The most efficient way to reduce EMI/RFI is to avoid them from the beginning. The switching losses of the IGBT will be a little higher but the total power loss of the whole inverter stage are lower compared to a standard straightforward driver where a snubber circuit is connected to the IGBTs and a large output filter is necessary (**Figure 3** and **Figure 4**).

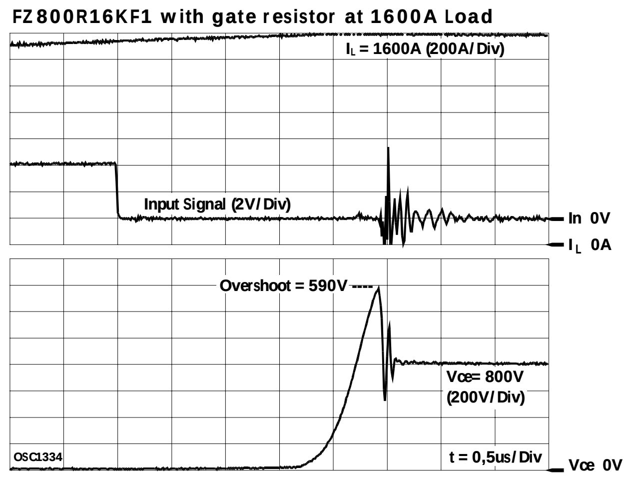

Figure 5
Turn-off with Gate Resistors

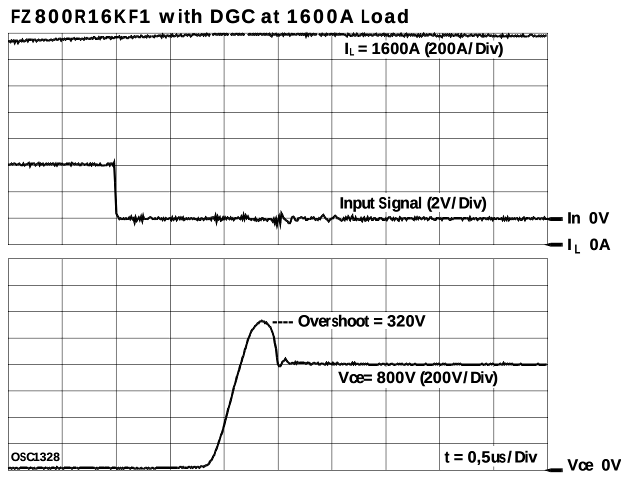

Figure 6
Turn-off with DGC

2.6 Short-circuit and Overcurrent Protection

A new short-circuit detection concept enables a very short reaction time of the DGC to detect a short-circuit. In case of a short-circuit the DGC turns off the IGBT within a few microseconds, much faster than most of the conventional protection systems will do. The advantages of the new system are:

- The short-circuit detection is independent from the overcurrent monitoring and therefore optimised for very fast detection.
- An immediate short-circuit cut-off reduces the thermal stress of the silicon and of the bond wire contact which result in an increased reliability of the power stage or in a much higher number of allowed short-circuit turn-offs.
- The DGC minimises the overvoltage spike during turn off of the high short-circuit current.

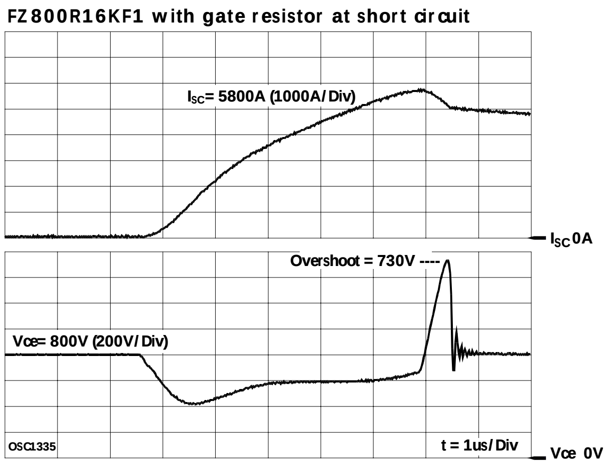

Figure 7
Short-circuit Turn-off with Gate Resistors

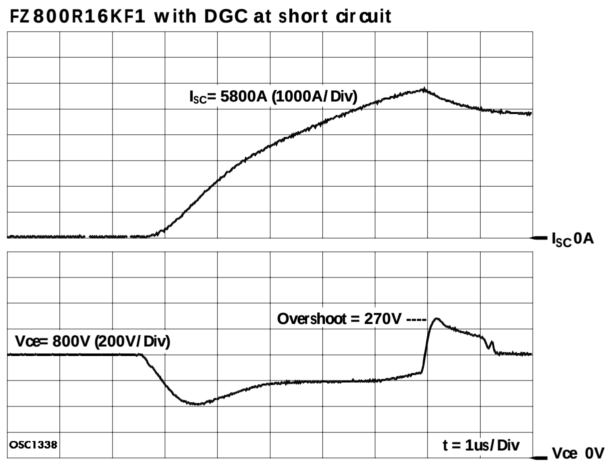

Figure 8
Short-circuit Turn-off with DGC

The overcurrent protection is realised via a V_{CE} monitoring. The V_{CE} trip level can be adjusted in such a way that the DGC turns off at 2 to 3 times nominal current. The actual trip level depends on the forward characteristic of the IGBT itself and can easily be adjusted to meet the requirements of the actual application (**Figure 9**).

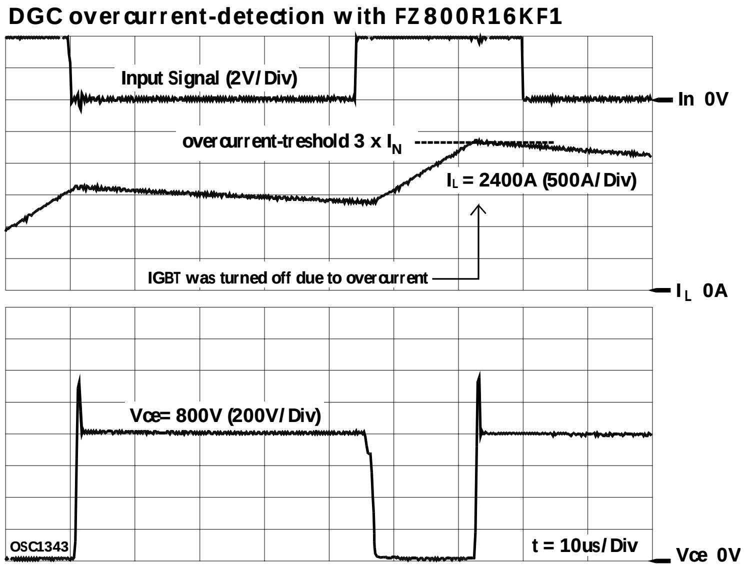

Figure 9
Overcurrent Detection and Turn-off

2.7 Carrier-Frequency Monitoring

A carrier frequency monitoring is implemented in the control logic of the DGC. This feature protects the IGBT from unacceptable carrier frequencies due to a faulty PWM controller or disturbances of the fiber-optic link between controller and DGC (**Figure 10**).

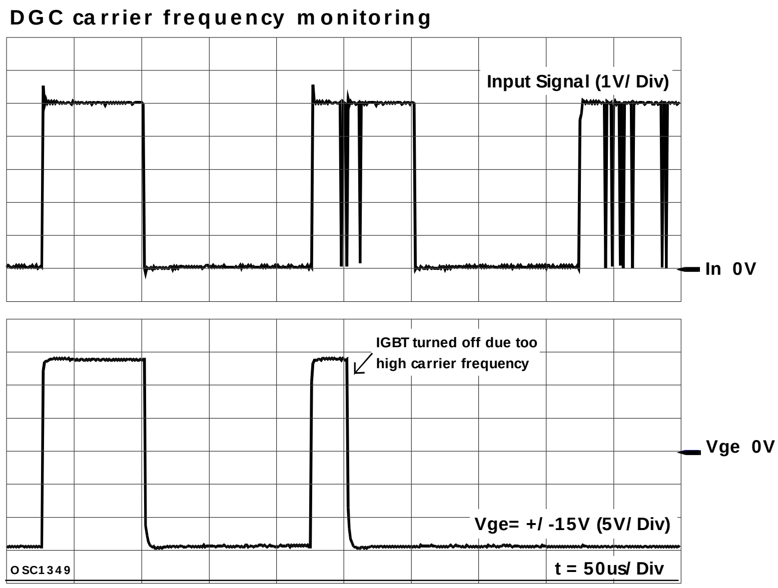

Figure 10
Turn-off Due to Carrier Frequency Failure

2.8 IGBT Status- and Diagnostic System (ISDS)

The control logic of the DGC enables a variety of feedback information from the DGC to the Microcontroller or host system. The simplest information is a "fault" signal as it is standard for most straightforward drivers. It indicates that the DGC has turned off due to some kind of failure. In advanced mode the DGC transmits a digital code to the controller which can indicate one or more of the following information:

- DGC has no supply voltage (fatal system breakdown)
- IGBT is turned-off (real-time information if IGBT is really in blocking mode)
- IGBT is turned-on (real-time information if IGBT is really in conduction mode)
- IGBT was turned-off due to overcurrent
- IGBT was turned-off due to short-circuit
- IGBT was turned-off due to too high carrier frequency

Using the ISDS the host controller exactly knows whether the IGBT has turned-on or off. Therefore the dead time between high and low-side switch can be reduced in such a way that, for example, the high-side switch will turn on if the DGC indicates that the low side switch has really turned off. The reduction of the dead time results in:

- a higher degree of modulation. In inverters the RMS value of the output voltage will be higher and in SMPS it allows a more detailed design of the transformer.
- The dynamic of the total system will be improved. This is important for 4Q-inverters because the magnetic flux of the motor will remain almost the same either for driving the motor or for regenerative braking.
- Oscillation of the IGBT collector voltage is minimised due to minimised dead time.

Figure 11 shows the set-up of a complete 3-phase inverter power stage suitable for traction applications or other high-power inverters (e.g. inductive heating). Together with a custom specific control chip (Multi-Phase Controller, MPC) the complete power stage can communicate directly with a microprocessor system via a standard µP bus architecture.

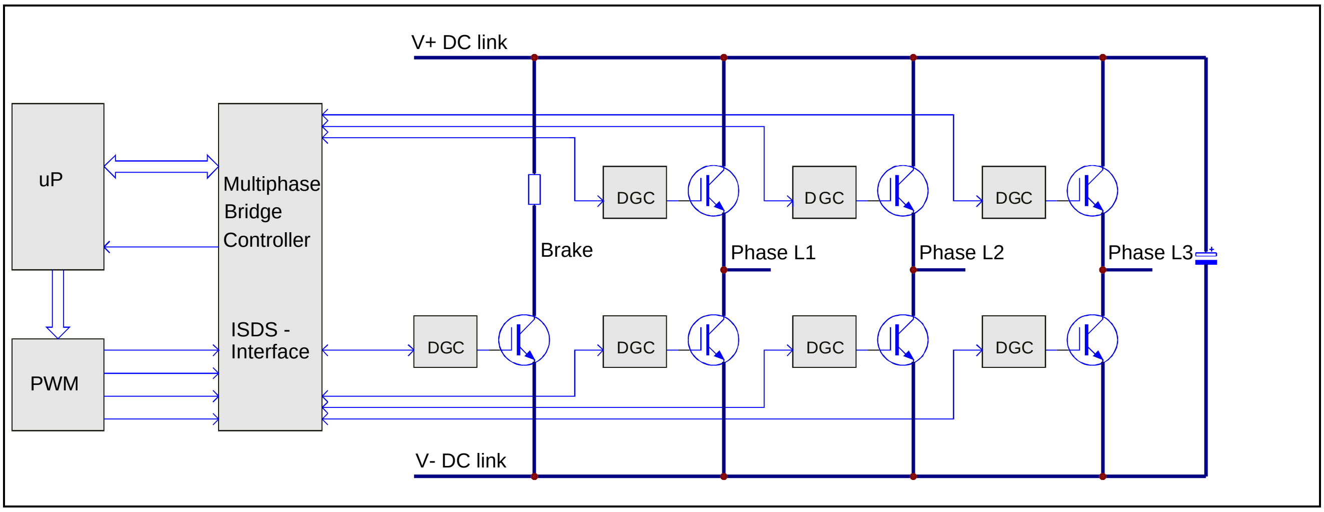

Figure 11
Complete µP Compatible High-power Inverter with DGC and MPC

2.9 Power Supply and Isolation

The DGC is supplied via a 16 kHz AC bus as it is usual for e.g. GTO driver units. The AC source may be supplied by the user of the DGC or is available as accessory. The galvanic isolation between AC bus and DGC is achieved by a transformer already implemented in the DGC.

3 Summary

As described the Dynamic Gate Controller is the perfect driver for available high power IGBTs with blocking voltages up to 1700 V and current ratings from 400 to 1200 A and above. The dynamic turn-on and turn-off control improves the overall system behaviour and allows the design of snubberless high-power IGBT inverters combined with reduced RFI/EMI emissions. The programmable interface to the host-system and the various protection systems enables the use of the DGC in almost every high-power IGBT power stage from DC choppers to AC inverters.

4 Future Trends

The new “open concept” of the DGC will allow the perfect adaptation of the DGC to future high-power IGBTs. If the new IGBT generation with blocking voltages up to 4500 V is available for the market the DGC will be ready for those devices. Special options will allow the perfect paralleling of IGBTs as well as the series connection without any dynamic snubber network.