System Solution Guide

# Industrial Motor Drive


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# Table of Contents

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# Overview

**Industry** Industrial – Industrial Drives, Robotics

**Applications**

Electric motors will continue to be widely used. They can be used in small home appliances, in industrial manufacturing and in heavy-duty applications. Their versatility allows them to be used for almost any purpose. Electric motors account for approximately half of the world's electricity consumption, with an ever-rising trend. Nowadays, with the intensifying drive to reduce carbon emissions, it is becoming increasingly crucial to enhance efficiency, through the implementation of novel control algorithms, utilization of new, more efficient motor architectures and by the incorporation of modern semiconductor technologies.

Industrial motor drives are the backbone of contemporary global industry. They account for almost two-thirds of the energy consumed in all industrial applications.

With the regulations becoming increasingly stringent, the necessity for substantial energy savings in industrial drives is becoming increasingly apparent. AC motors can typically be driven directly from the mains AC supply. However, for enhanced efficiency and superior control, a variable frequency drive implementation is required.

An industrial drive system that uses variable frequency drive (VFD) is more efficient than system utilizing conventional throttle control. onsemi offers a wide variety of products for VFD including MOSFETs, IGBTs, diodes, power integrated modules (PIM) and intelligent power modules (IPM).

Other components and technologies used in the subsystems include gate drivers, operational amplifiers, position sensors, temperature sensors and other used for control and sensing

The efficiency and longevity of motor drives are increased by usage of modern semiconductors and novel motor architectures.

Industrial drives are employed in a multitude of industrial sectors including process automation, fan control, liquid and gas pumps, robotics, material handling, machine tools, the oil and gas industry, and others.

# System Description

## Opportunities for CO2 Reduction

The utilization of electric motors ranges from small to heavy-duty applications. Various sources indicate that electric motor drives consume approximately half of the globally generated electricity. Industrial applications account for almost one-third of the world's electricity production. It is expected that the increasing automation in the industrial field will lead to an increase in the number of industrial motor systems. Nowadays, sustainability and energy efficiency are becoming important topics of discussion. It is therefore crucial to both update existing solutions and newly deployed systems achieve the highest possible efficiency.

The market of industrial motor drives is expected to grow at an average compound growth rate (CAGR) of 5 to 5.5% from 2024-2029, from 25.5 billion to 32.7 billion $. Incentives to grow include rapid industrialization in developing economies. The market is currently pushed into process optimization and energy efficiency. Electric drives tend to be much more efficient and require less maintenance than other solutions, such as gas turbines.

The 2020 Motor System Market Assessment (MSMA) report indicates that motor drive systems in the USA offer more than 5 billion USD and more than 43 million metric tons of CO2 annual savings opportunity. The main points for improvement are controllers and motors.

The motor controllers can be improved by implementing a variable frequency drive (further explained below), which significantly improves efficiency under varying loads. In the past a lot of deployed systems were overrated. This resulted in a longer operational lifetime, but on the other hand it decreased the overall efficiency of the system. Implementing load matching and variable frequency drive could achieve an efficiency increase of more than 10%.

The aforementioned 2020 MSMA report indicates that the incorporation of more efficient motors, such as permanent magnet synchronous motors, can result in the annual saving of 45,000 GWh of electricity in the United States alone. The integration of wide bandgap (WBG) semiconductors further increases the efficiency of the system, although at the cost of higher initial investments. Their other advantages include higher operating temperature, higher operating voltages and higher switching frequencies, which can reduce the size and cost of passive components.

## Variable Frequency Drive

The majority of modern three-phase motors, which are widely used in robotics, industrial and other demanding applications, are driven by power switches. The systems commonly use a pulse width modulation (PWM) signal to determine the commutation between the ON and OFF states. This is called variable frequency drive (VFD), and it is much more efficient than conventional throttle control, saving energy mainly with varying load.

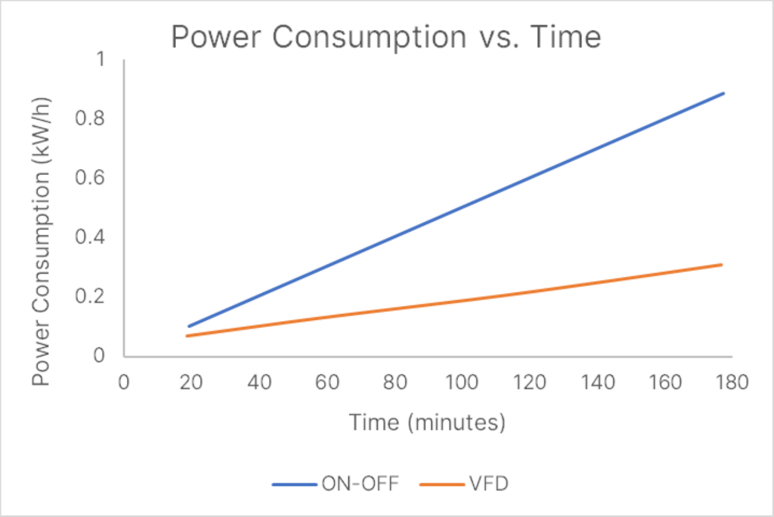



*Fig.1: Effect of variable frequency drive on power consumption*

Sources: Mordor Intelligence, IMARC Group, 2020 MSMA

# System Description

## Commonly Used Motor Types

Previously widely used DC motors use mechanical brushes for commutation between stator and rotor, which causes higher noise, a greater need for maintenance, lower efficiency and inferior thermal performance. In contrast, brushless motors are electronically commutated and are therefore more efficient, quieter, require little to no maintenance and have a longer lifetime. However, their control is more complicated. The three most prevalent types of the AC motors are: AC induction motors (ACIM), permanent magnet synchronous motors (PMSM), and brushless DC (BLDC) motors.

AC induction motors consist of stator with multiple windings and a rotor constructed from multiple conductive bars. When an AC current is applied to the stator windings, a rotating electromagnetic field is created in accordance with Faraday's Law. This rotating electromagnetic field induces currents in the rotor windings. The induced currents in the rotor create magnetic field that reacts against the stator field. The direction of the induced magnetic field reacts against the stator field producing a force that causes the rotor to rotate in the direction of the stator's magnetic field. Since rotation at synchronous speed does not induce rotor current, an induction motor always operates slightly slower than synchronous speed. This difference between synchronous speed and operational speed of the rotor is referred to as "slip" or slip angle. The typical slip value is between two and six percent. This is the reason why ACIMs are considered asynchronous. The speed of the AC induction motors can be controlled by modifying the frequency of the input current, for instance by utilizing variable a frequency drive (VFD).

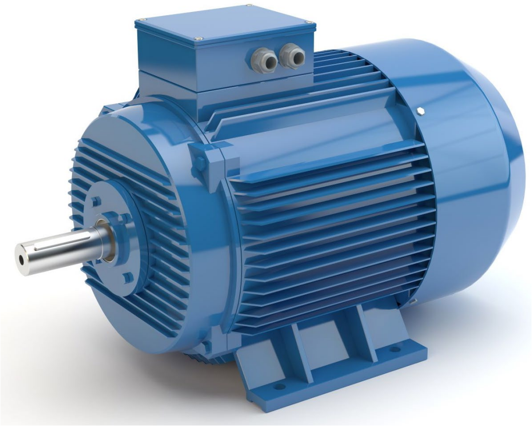


*Fig.2: AC induction motor*

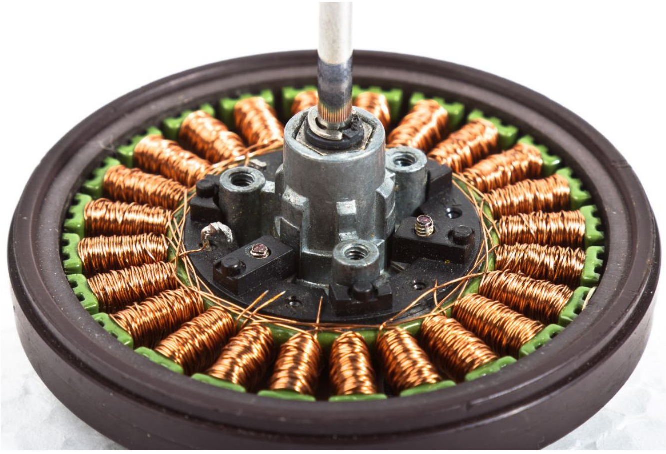


*Fig.3: Brushless DC motor*

Permanent magnet synchronous motors (PMSM) and brushless DC (BLDC) motors utilize the same stator as ACIM, but their rotors contain permanent magnets. This eliminates the need for induction, thereby increasing efficiency. In this type of motor, the rotor speed is equal to the speed of the stator's electromagnetic field, hence the synchronous operation. The distinction between PMSM and BLDC lies in their respective control and their back-electromotive force (BEMF) response. The BLDC BEMF response is trapezoidal while that of PMSM is sinusoidal.

ACIM and PMSM/BLDC are commonly used in heavy-duty applications like conveyor belts, material handling systems, pumps and compressors. They are ideal for continuous operation and when precise speed and torque control are required. One disadvantage of these motors is their higher cost due to the inclusion of permanent magnets.

*Table 1: Comparison of AC induction motors and permanent magnet synchronous/brushless DC motors*

| Type | Pros | Cons |
|---|---|---|
| AC Induction Motor | • Low cost<br>• Self-starting<br>• Reliable<br>• Easy to control<br>• Easy brake implementation<br>• More peak power | • Higher losses<br>• Heavier<br>• Loss of torque at high speeds |
| Permanent Magnet Synchronous/ Brushless DC Motors | • Compact size<br>• Able to stop frequently without overheating<br>• Lightweight<br>• Magnetic field intrinsic to permanent magnets | • Expensive<br>• Lower efficiency at high speeds due to eddy currents<br>• No easy way to change magnetic field strength<br>• More complicated control |

Stepper motors and servo systems are used for the precise positioning and controlled movement. They are widely used in applications requiring the holding and positioning. They are employed to power robot arms, assembly lines, lift-assist devices and other similar applications. The systems are characterized by their high degree of accuracy and substantial repeatability.

A stepper motor is typically composed of a rotor with a permanent magnet and multiple teeth, which determine the number of steps. The stator also contains teeth, although fewer than those on the rotor. These are distributed in a way that some are aligned with those on the rotor, and some are misaligned. The stator coils are divided into two independent sets. When energized, the coils create a magnetic field which causes the rotor to make exactly one step by aligning the teeth. By repeatedly energizing the two sets of coils, a highly precise motion can be achieved without the need for any feedback, which is referred to as open loop control.

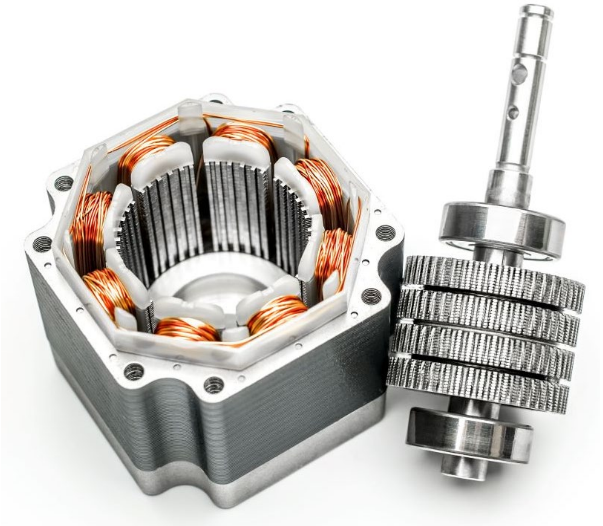


*Fig.4: Stepper motor – notice the teeth on stator and on rotor*

Stepper motor drives can be unipolar or bipolar. Bipolar stepper motors permit the current to flow in both directions and require a full-bridge inverter to drive each of the two sets of windings. In contrast, unipolar stepper motors require only one direction of current flow, simplifying their control. Such motors may be controlled by simple high- or low-side switches, offering a more cost-effective option.

A servo motor operates within a closed-loop control system. The system employs feedback from an encoder to compare the actual position of the motor to the required value. The closed-loop ensures precise positional control. A Servo motor system consists of three main parts: the motor, the feedback device and the control circuit. The motor generates the mechanical power and can be either brushed DC, or BLDC, PMSM or even ACIM. The feedback device provides information about the motor's position, torque and speed. The control circuit compares the required position with the actual position and adjusts the output to correct any discrepancy.

*Table 2: Comparison of stepper motors and servo motor systems*

| Type | Pros | Cons |
|---|---|---|
| Stepper Motor | • Simple to control<br>• High torque at low speed and when stationary<br>• Less expensive | • Less torque at high speed<br>• May lose steps at high speeds<br>• Can be noisy |
| Servo Motor | • Continuous rotation<br>• Higher precision due to closed-loop<br>• High torque at wide range of speeds | • More expensive<br>• More complex<br>• Limited torque when stationary |

## Motor Control Techniques

The trapezoidal control algorithm also known as the six-step control, is the simplest control algorithm. It involves the current flowing through two phases at a time, with the third phase floating. There are six discrete states applied to the motor. This method generates high torque, but it has higher noise and vibrations than other more advanced algorithms.

In sinusoidal control the current waveform applied to the motor windings is sinusoidal. This results in reduced torque ripple. However, it is more complex to implement since it requires precise synchronization and identifying the rotor position.

Field oriented control (FOC) provides better efficiency at high speeds compared to sinusoidal control. It offers superior performance on dynamic loads in comparison to the aforementioned techniques. It optimizes motor torque by maintaining ninety-degree alignment between the stator and rotor throughout the entire commutation, reducing torque ripple and resulting in smoother, quieter rotation.

## Rotor Position Detection

The most common method of detecting rotor position is through the utilization of Hall effect sensors. As the rotor passes the Hall effect sensor, it provides information about the position of the magnet poles to the controller. The Hall effect sensors are typically distributed at 120 degrees apart.

In sensorless applications, the back-electromotive force (BEMF) is measured to determine the rotor position and switching signals. A comparison of Hall sensors and back emf can be seen in Figure 5.

Other possibilities include the use of optical or inductive sensors to obtain accurate information about the position of the rotor.

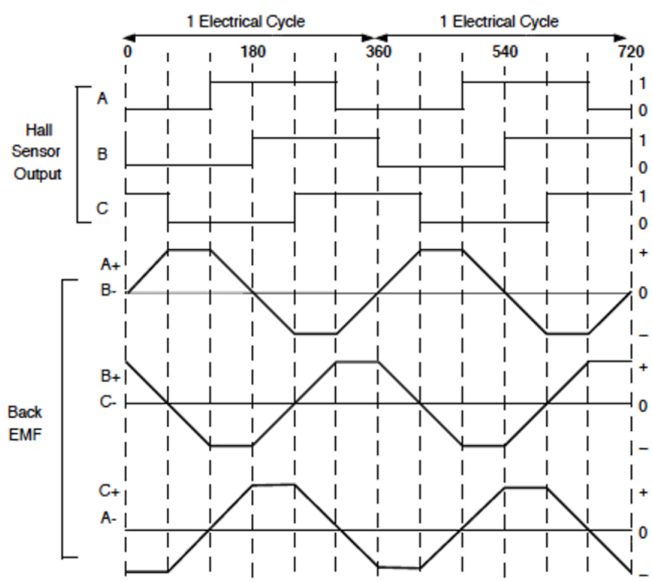
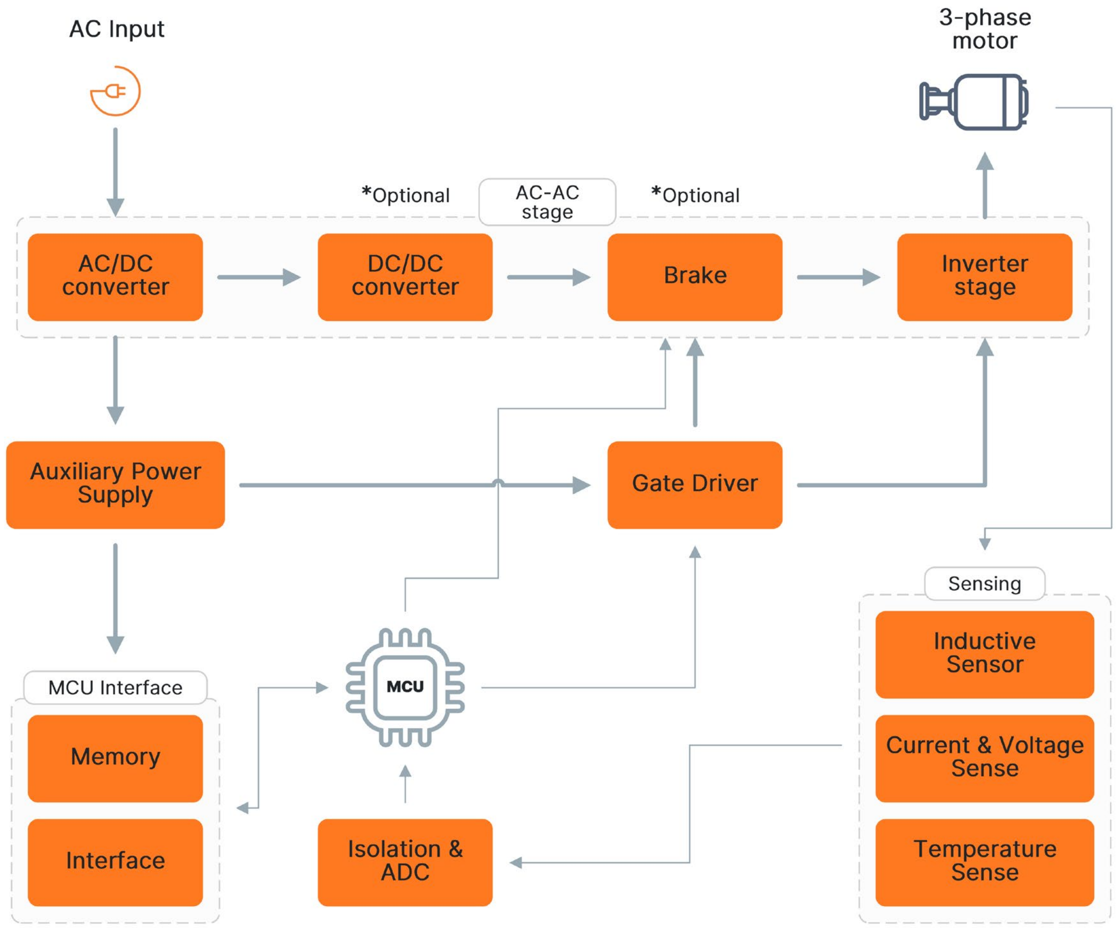



*Fig.5: Comparison of Hall sensor output and measured back electromotive force*

# Solution Overview

## Motor Drive Top Level Topology

Block diagram below represents industrial motor drive solution recommended by **onsemi**. Most important building block is AC-AC stage. In the past considerable number of motors were directly powered from mains, but it is more efficient to use AC/DC converter and then inverter stage. Other important parts include control unit, which contains algorithm and controls whole system, sensing which delivers feedback and auxiliary power supply providing low voltage rails.

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## Motor Drive Architecture

The general architecture of a grid-powered motor control circuit consists of the following elements: a rectifier, power supplies, sensing, control hardware and a power stage.

The rectifier stage is responsible for converting alternating current (AC) into direct current (DC). This can be achieved using a simple diode bridge, but in order to increase the efficiency and power factor (thus reducing reactive power) of the system, power factor correction stage can be used. An optional DC-DC stage is used to convert the DC voltage to the voltage required by the motor. Auxiliary power supplies convert the AC input or DC bus to different low voltages into supply control hardware (MCU, memory, interfaces, etc.) and also gate drivers.

A brake circuit is utilized to dissipate energy during deceleration. When the motor is disconnected from the power supply, it starts to act as a generator. Dynamic braking takes advantage of a braking resistor connected in series with a power switch (typically an IGBT), to dissipate the power from the motor.

An inverter is composed of power switches that transfer power to the motor. Depending on the power level, they can be Si MOSFET, IGBT or silicon carbide (SiC) MOSFET. They can be discrete, in the form of a power module or modules with integrated gate drivers.

In order to perform accurate electronic commutation, it is necessary to ascertain the position of the rotor. This has been traditionally achieved by utilizing a Hall sensor. More novel solutions use optical or inductive sensors, while some solutions skip the sensor and measure back electromotive force. Inductive position sensors such as the NCS32100 are especially useful during start-up, when the exact position of the rotor needs to be known. It is possible that the position was altered during the period of downtime, and the system is therefore unable rely on the last known state.

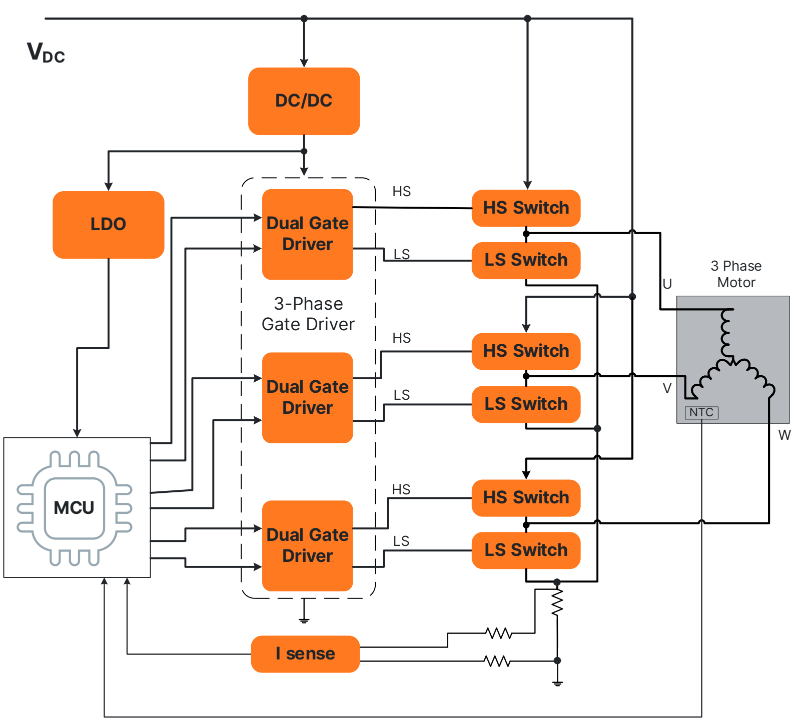


*Fig.6: Example of three phase motor discrete control and power stage block schematic*

### Inductive Sensing NCS32100

- Calculates position and velocity
- **Absolute encoder** – no movement needed to determine its position
- 6,000 RPM full accuracy (45,000 maximum RPM)
- +/- 50 arcsec (0.0138 degree) or better accuracy for a 38mm sensor – see figure 16
- Can differentiate and reject the vibrations from the rotational movement
- Integrates CortexM0+ MCU – highly configurable
- Cheaper alternative for a wide range of the optical encoders

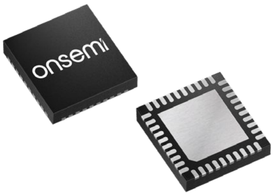


*Fig.7: QFN-40 package*

## Power Factor Correction

The power factor correction (PFC) stage is an AC/DC converter. Its objective is to shape the input current to match the shape of the input voltage. This reduces the harmonics and improves the efficiency.

The PFC stage is typically implemented by inserting a boost converter stage between the rectifier bridge and the input capacitor. In single-phase applications, interleaved boost (Figure 7) or totem pole PFC can be used. These topologies can usually be used for powers up to 2 kW depending on the used controller and conduction mode.

Totem pole PFC (figure 10) replaces bridge diodes with active switches to reduce losses. The totem pole PFC stage consists of a fast-leg (switched at high frequency, 100 kHz or more) and a slow-leg (switched at mains frequency). In the fast-leg, wide bandgap semiconductors are preferred, as they allow higher switching frequency, thus reducing the size of the passive components. As a slow-leg switch, an IGBT can be used.

For three-phase high-power applications, the Vienna rectifier, active front end, or power module with integrated PFC is ideal. The Vienna rectifier (Figure 8) has high efficiency but higher cost due to the number of required power switches and more complicated control. For further insight into various PFC topologies refer to [Demystifying Three-Phase Active Front End or Power Factor Correction (PFC) Topologies.]

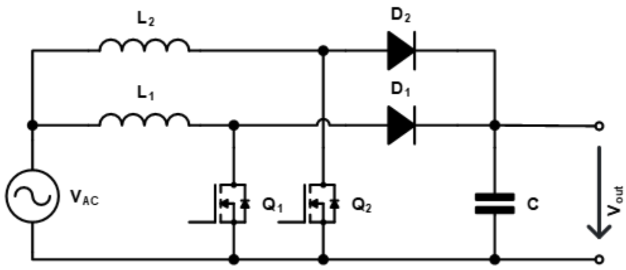


*Fig.7: Single-phase two-channel interleaved boost converter*

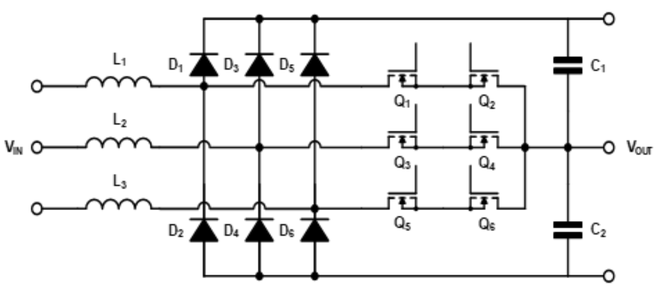


*Fig.8: Three phase Vienna rectifier*

## Power Factor Controllers [NCP1681]

Bridgeless Totem Multi-Mode PFC Controller

- Fixed frequency CCM (Constant Conduction Mode) with Constant on-time CrM and valley switching frequency foldback
- Proprietary Current Sense Scheme
- Proprietary valley sense scheme
- Ideal for high power: Multi-Mode applications up to 1kW, CCM >2.5kW
- SOIC-20 package

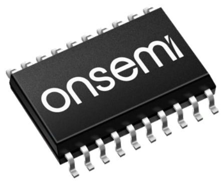


*Fig.9: SOIC-20 package*

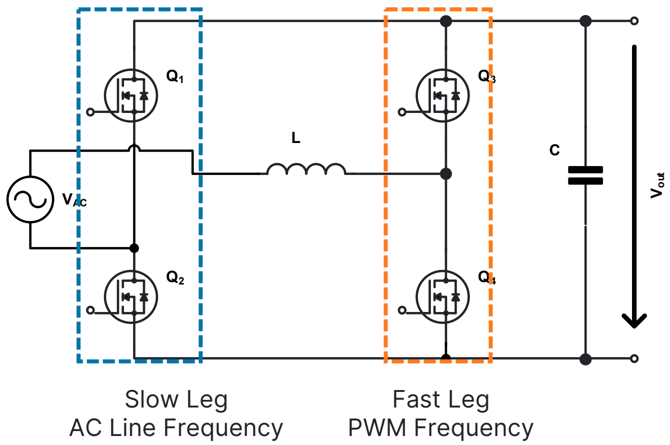


*Fig.10: Totem Pole PFC schematic*

## Inverter Switch Variety

A motor control system can be designed using discrete components (IGBT, Si MOSFET, SiC MOSFET, diodes, gate drivers, etc.) or power modules, which integrate multiple parts. These modules can integrate a three-phase half bridge, one half bridge, or even include a brake, PFC, or gate driver in one package.

Suitable power switch from onsemi can be selected from figure 11, depending on the application, desired power, and motor voltage. Discrete solutions using IGBT or SiC can be utilized for single phase applications up to approximately 5 kW. Power modules can be divided into power integrated modules (PIM), and the intelligent power modules (IPM). The use of modules offers numerous advantages over the discrete solutions.

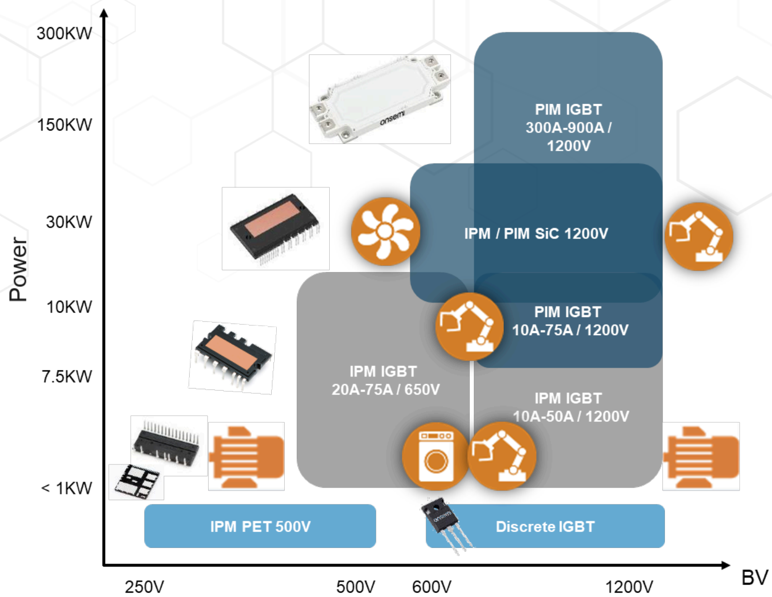


*Fig.11: Recommended inverter solution depending on the desired power level and bus voltage*

Since modules integrate power components as well as protections (such as UVLO, short-circuit protection, thermal sensing, etc.) they reduce required space and are more reliable since they are fully tested. onsemi offers modules in SiC and IGBT technology in various packages and with numerous topologies and features.

Power integrated modules integrate the discrete output stage and AC/DC converter into a single part. Some of the PIMs integrate a brake, which is why they are known as converter inverter brake (CIB) PIMs. PIMs still require separate and suitable gate drivers.

Intelligent power modules, in addition to the inverter stage, also include gate driver and protection. They greatly reduce the system size and time to market. An example of an onsemi IPM and its elements is illustrated in the figure 12.

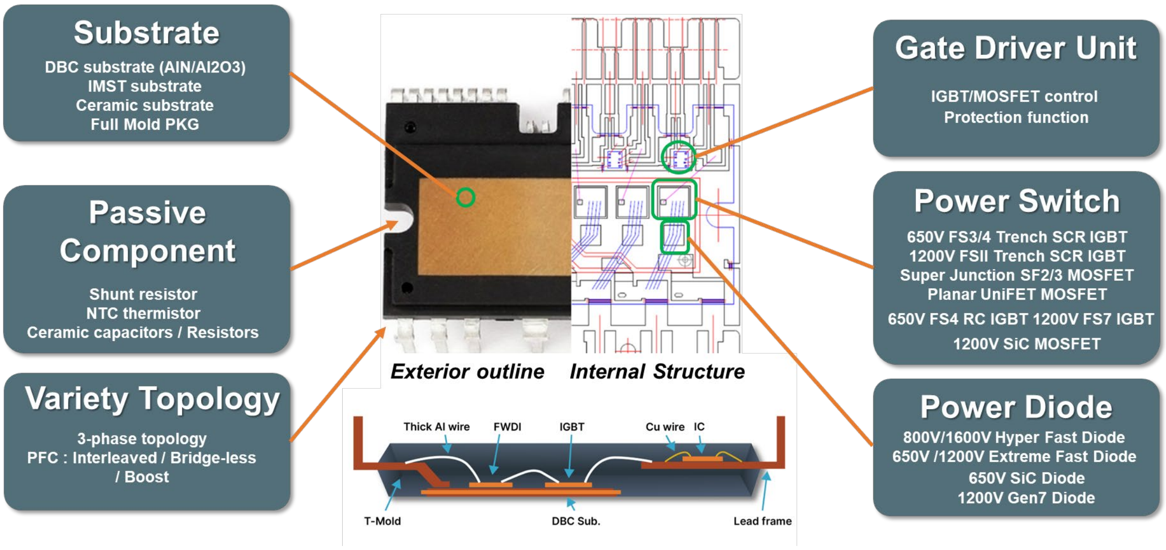


*Fig.12: Level of integration of* ***onsemi*** *Intelligent power module*

## IGBT – Cost-effective High-voltage Switch

IGBTs are optimal for high-voltage applications, as they provides a higher blocking voltage for equivalent material thickness, compared to the Si MOSFETs. IGBT switches are cost-effective and mainstream solution. Their disadvantage is that they have a lower possible switching frequency, which means that the used inductors would be larger. IGBTs have a long history of driving motors at frequencies up to 20 kHz.

### Field Stop VII, IGBT, 1200V

- New Family of 1200 V Trench Field Stop VII IGBT
- Low VCE(SAT) type for motor control applications – increases the power that can be handled and decreases the power losses generated as heat and thus improves cooling
- Improved parasitic cap for high-frequency operation, high ruggedness
- 1200V Gen7 diode for low VF and softness – lower voltage drop decreases the conduction losses and softness refers to the reverse recovery of the diode. The softer is the reverse recovery the less noise and fewer electromagnetic interference (EMI) issues

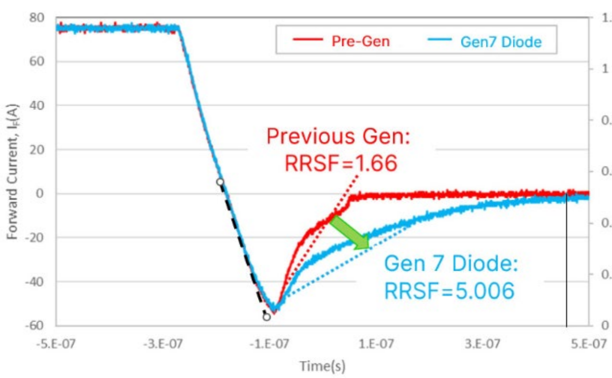


*Fig.13: Comparison of softness of Gen7 and previous Gen diode*

Diode softness is defined as diode recovery softness factor (RRSF),

$$RRSF=\frac{\left|\frac{dI_{rise}}{dt}\right|}{\left|\frac{dI_{fall}}{dt}\right|}$$

where $dI_{rise}/dt$ is the maximum slope when reverse current rise from 0 to peak during turn–off, $di_{fall}/dt$

is the maximum slope the reverse current falls from peak to 0. As Figure 13 shows, latest Gen7 diode has softness of 5, three times improved than previous generation. See more in Advanced Industrial Motor Control for Increased Power Efficiency.

### IGBT FGY100T120RWD

- 1200V, 100A IGBT from FS7 family
- Integrated Gen7 diode
- $V_{CE(SAT)}$ = 1.4V, $T_{jmax}$ = 175°C
- Positive temperature coefficient for easy parallel operation
- Low conduction loss and optimized switching for motor control applications

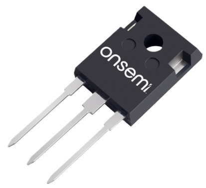


*Fig.14: TO-247-3 package*

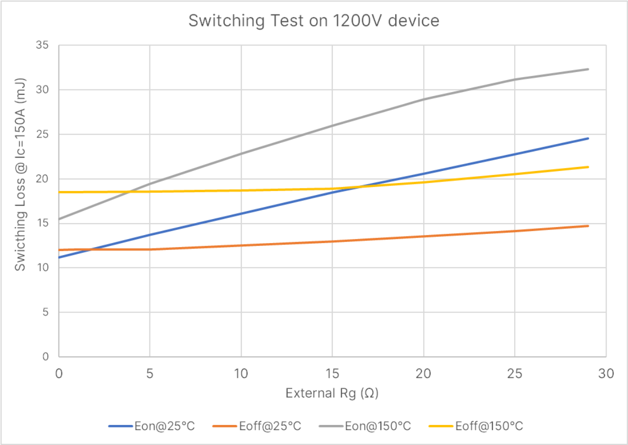


*Fig.15: Switching losses of 1200V IGBT from FS7 family*

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# Solution Overview

## EliteSiC MOSFET – Best Performance

The SiC MOSFETs offer the best performance for applications requiring high voltage and high frequencies. Silicon carbide is a wide band gap semiconductor. Due to inherent material properties such as higher electron mobility, lower intrinsic carrier concentration, and higher thermal conductivity. The comparison between the material can be seen in Table 3. Compared to silicon, SiC MOSFETs offer higher current densities, reduced switching losses, and simplified cooling systems. The efficiency of the system using SiC technology is improved by reducing conduction losses. EliteSiC is the brand name of onsemi's SiC technology. The EliteSiC MOSFETs are available with a breakdown voltage ranging from 650V to 1700V. All families of EliteSiC SiC MOSFETs exhibit no drift in RDS(ON), VTH, or diode-forward voltage over a lifetime due to a special planar design.

### SiC MOSFET NTH4L014N120M3P

- EliteSiC MOSFET from new 1200V M3P Family, ID = 152 A, in TO-247-4L package
- Low switching losses - Typ. EON 1308 μJ at 74 A, 800 V
- RDS(ON)=14 mΩ @VGS=18 V
- Ultra low gate charge (QG(TOT))=137 nC
- High-speed switching with low cap. (COSS=146 pF)


*Fig.16: TO-247-4L package*

### SiC MOSFET NTH4L023N065M3

EliteSiC MOSFET from new 650V M3S Family

**Key Features:**

- Improved switching losses
- Optimized for high temperature operation
- RDS(ON)=22.6 mΩ @VGS=18 V
- Ultra low gate charge (QG(TOT))=87 nC
- High-speed switching with low cap. EliteSiC MOSFET from new 650V M3S Family (COSS=153 pF)
- TO-247-4L package

Learn more about M3 family - AND90204 - onsemi EliteSiC Gen 2 1200 V SiC MOSFET M3S Series

*Table 3: Comparison of Silicon and Silicon Carbide material properties*

| Electrical Property | Silicon | Silicon Carbide |
|---|---|---|
| **Bandgap (eV)** | **1.12** | **3.26** |
| **Critical Electric Field (MV/cm)** | **0.3** | **3.0** |
| **Saturated Electron Velocity (x10$^7$ cm/s)** | **1** | **2** |
| **Thermal Conductivity (W/cm*K)** | **1.3** | **3.3** |

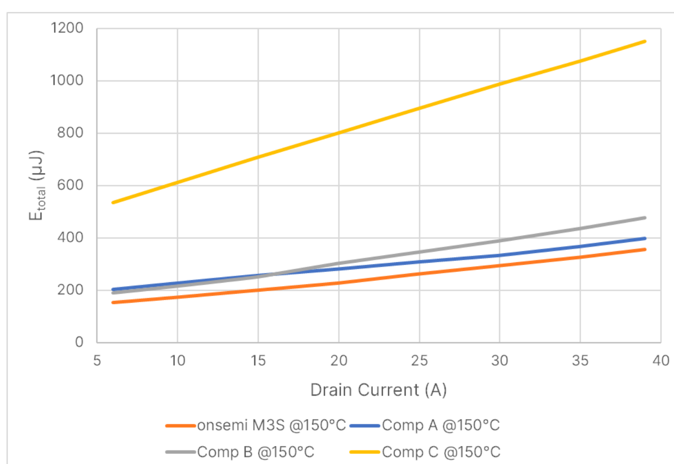


*Fig.17: Total switching losses comparison at VDC=400V, VGS=18/-3V, RG=4.7Ω*

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## Intelligent Power Modules – Highly Integrated and Reliable

Intelligent Power Module (IPM) is a power switch with the highest degree of integration currently available. The switch is either an IGBT or a Si MOSFET. It is a popular choice for motor control application due to the fact that it is capable of including the entire inverter and PFC stage in a single package. Further advantages include EMI improvements, space optimization and easier thermal design. Refer to figure 19 to see highlights of the onsemi IPM portfolio.

### Intelligent Power Module NFCS1060L3TT

- Fully integrated PFC and inverter stage in one package
- Includes PFC SJ MOSFET, six drive IGBTs
- 600V, 10A
- Built-in over-current and cross-conduction protection
- Built-in bootstrap diodes and NTC
- Reduced PFC inductor size
- Simplified  heatsink design
- Reduced EMI

### Intelligent Power Module NFAM3065L4B

- High-performance output stage for ACIM/BLDC/PMSM
- Integrates high side and low side gate drivers, six IGBTs
- 650V, 30A
- Built-in over-current and low voltage protection, thermal monitoring and
- Built-in temperature sensor
- Reduced EMI and losses

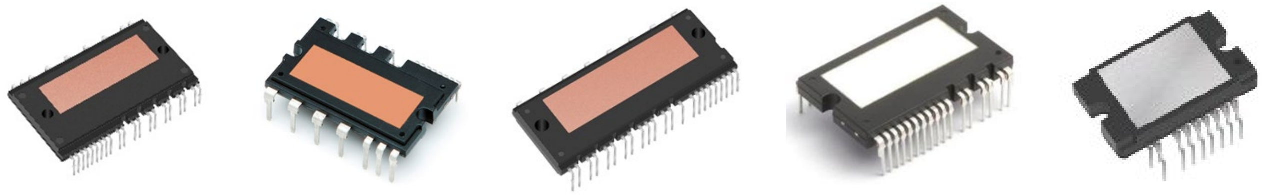


*Fig.18: variety of **onsemi** IPM packages*

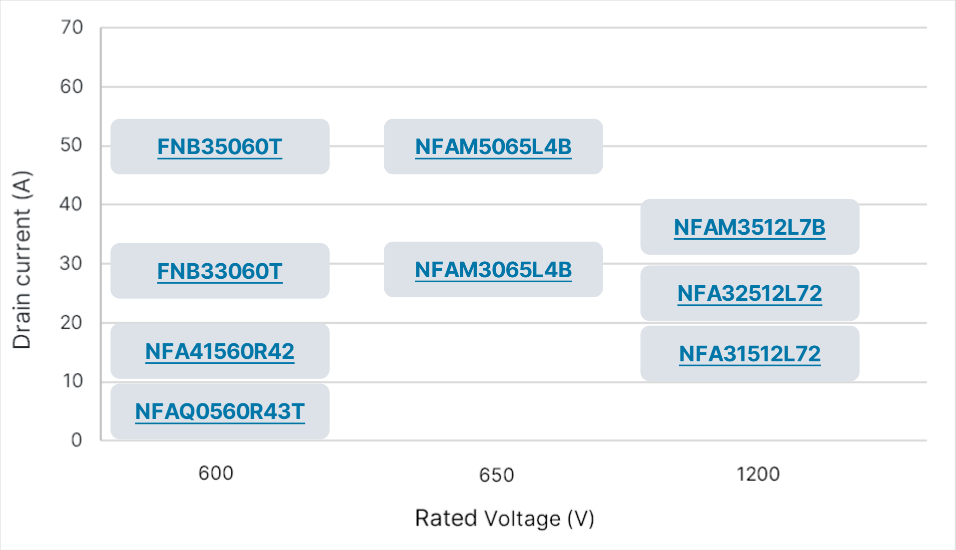



*Fig.19: **onsemi** IGBT IPM portfolio*

# Solution Overview

## Power Integrated Modules (PIM) – Highest Power

**onsemi** offers power integrated modules that utilize SiC MOSFET and IGBT technologies. They enable design improvements and can be used at up to 1200V.

IGBT devices still remain the primary choice due to their high voltage, high current capabilities and lower cost. Their main disadvantage – low switching speed, is of less importance in motor control applications.

SiC devices offer the best performance and power density and are being adopted rapidly. Lower switching losses enable higher efficiency with less cooling efforts or higher switching frequency with reduced size and cost of passive components. These benefits can justify the higher costs of SiC power devices.

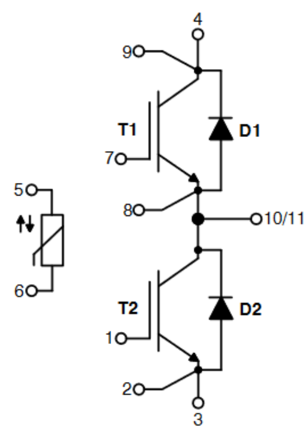
PIMs can include half-bridge, full-bridge or even whole three-phase inverter in one package. Using modules greatly reduces design time, cooling size and increases overall integration.

*Table 4: Power Integrated Modules for motor control*

| SiC Half-Bridge (2-Pack) Modules | IGBT Based PIM Modules |
|---|---|
| Half-Bridge SiC Modules | Available PIM Modules |

NXH800H120L7QDSG is a **1200V, 800A rated IGBT Half-Bridge** power module. PIM11 (QD3) Package.

- New Field Stop Trench 7 IGBT technology and Gen. 7 diodes provide lower conduction losses and switching losses, enabling designers to achieve high efficiency and superior reliability.
- NTC thermistor included
- Low inductive layout



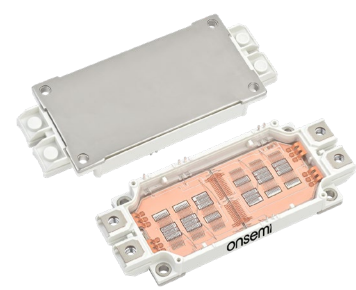
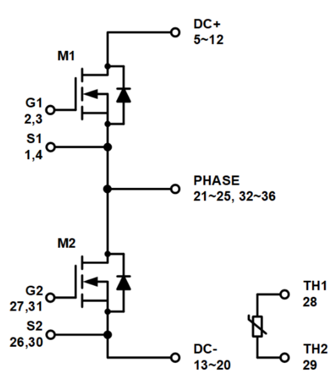




*Fig.20: left -NXH800H120L7QDSG schematic, right – PIM11 package*

NXH006P120M3F2PTHG is a **1200V SiC Half-Bridge module** in an F2 package.

- M3 EliteSiC technology provides typical $R_{DS(ON)}$ = 6 mΩ at $V_{GS}$=18V, $I_D$ = 100A.
- Thermistor included
- HPD direct bonded copper substrate



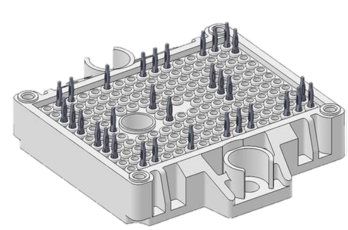



*Fig.21: left -NXH006P120M3F2PTHG schematic, right – F2 package*

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## Elite Power Simulator Powered by PLECS®

PLECS is a system-level simulator that facilitates the modelling and simulation of complete systems with optimized device models for maximum speed and accuracy. PLECS differs from SPICE-based circuit simulators, which focus is on the low-level behavior of circuit components. The PLECS models, referred to as “thermal models”, are composed of lookup tables for conduction and switching losses, along with a thermal chain. During the simulation process, PLECS employs interpolation and extrapolation, using the loss tables to determine the bias point conduction and switching losses associated with the circuit operation.

The Elite Power Simulator offers a wide range of AC/DC, DC/DC and DC/AC topologies. Additionally, onsemi offers the industry first Self-Service PLECS Model Generator allowing the user to create custom models which can be used in the Elite Power Simulator.

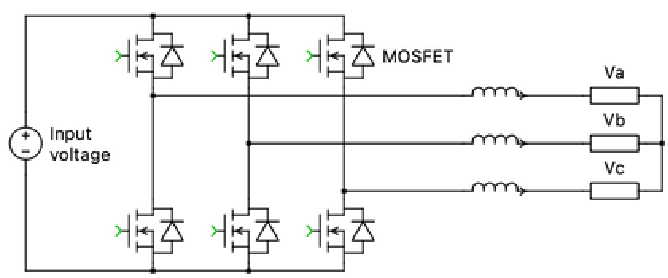


*Fig.22: three phase two level inverter topology in Elite Power Simulator*

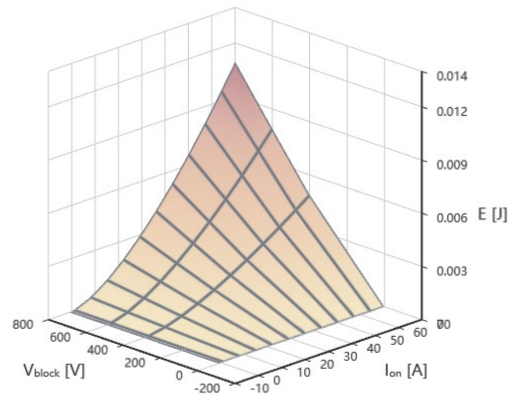


*Fig.23: IGBT turn on switch losses @75°C*

PLECS offers a range of inverter topologies suitable for industrial motor control including half bridge, full bridge and three-phase inverter.

After selecting the desired topology, the user can modify the voltage and power ratings of the circuit and select a power switch. Currently, PLECS is limited to SiC MOSFETs and power modules, FS7 IGBTs and T10 silicon MOSFETs. Subsequently, the user can observe the losses and thermal data of the device in the graph (figure 23) and in the table.

The simulation results (figures 24 and 25) can be saved and compared to a previous simulation with altered parameters or device. The data from the simulation can be exported and further evaluated.

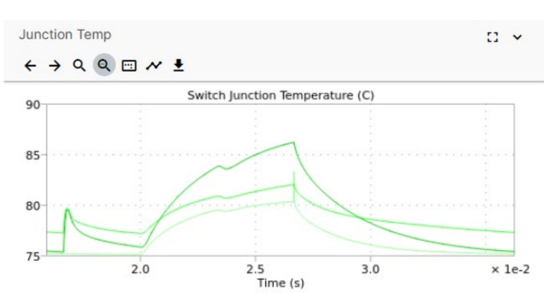


*Fig.24: Switch junction temperature comparison @75°C*

Losses Breakdown

| | FGHL40T120SWD, Nominal loss data, Trace 1 | NXH030P120M3F1PTG, Nominal loss data, Trace 1 | NTBG060N090SC1, Nominal loss data |
|---|---|---|---|
| Turn-on Losses | 0 W | 0 W | 0 W |
| Turn-off Losses | 0.32 W | 0.01 W | 0.01 W |
| Recovery Losses | 0.00 W | 0.00 W | 0.00 W |
| Forward Conduction | 53.44 W | 26.54 W | 33.45 W |
| Reverse Conduction | 0 W | 0 W | 0 W |
| (Body) Diode Conduction (Deadtime) | 1.05 W | 2.76 W | 3.25 W |

*Fig.25: Losses breakdown @75°C*

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## Gate Drivers – Importance of Correct Gate Drive Voltage

The MOSFETs and IGBTs must be driven by the gate drivers as the MCUs, or controllers are unable to drive them directly. The gate driver can be either a single half-bridge, driving one high-side and one low-side switch, or it can incorporate three half-bridge gate drivers, controlling all three motor phases.

It is recommended to use isolated gate drivers for high power applications, as they prevent ground loops that can cause noise. A potential risk to the system's safety arises when the grounding of both circuits is at different potentials. Isolation helps to protect from and safely withstand high voltage surges that could damage equipment or harm humans. It also helps to protect control systems. Furthermore, the isolation helps improving the communication with high-side components in high-voltage solutions.

*Table 5: Recommended gate drive voltage*

| | Si MOSFET/IGBT | SiC MOSFET |
|---|---|---|
| Turn-on | 10 to 15V | 15 to 20V |
| Turn-off | 0V | -2 to -5 V |

The operating voltage of the gate drive is determined by the specifications of the power switch. It is imperative that the positive voltage must be high enough to ensure the gate is fully turned on. Additionally, it is crucial to ensure that it does not exceed the maximum gate voltage of the device. When the gate voltage is 0V, it can generally fulfil the turn-off condition for all devices.

The switching losses of SiC MOSFETs can be reduced by utilizing a negative bias during the turn-off phase. This also helps preventing accidental turn-on during turn-off process. Many gate drivers from **onsemi** portfolio support external negative bias, where using external circuit provides negative bias to the gate driver.

The new NCP51752 family has internal negative bias, which saves system costs because the system does not have to supply the negative bias rail to the gate driver. Further information on the benefits of negative gate drive bias can be found in the onsemi EliteSiC Gen 2 1200 SiC MOSFET M3S Series and in Choosing the Right Silicon Carbide Gate Driver.

*Table 6: **onsemi** EliteSiC MOSFETs portfolio and corresponding isolated gate drivers*

| EliteSiC MOSFETs | | 1-channel (source/sink) | | 2-channel (source/sink) | |
|---|---|---|---|---|---|
| $V_{(BR)DSS}$ | $R_{DSON}$(typ) | 6.5A/6.5A | 4A/6A | 6.5A/6.5A | 4.5A/9A |
| 650V | 12-95mΩ | NCD57090 | NCD57000<br>NCD57001 | NCD575xx | NCP51560<br>NCP51561<br>NCP51563 |
| 750V | 13.5mΩ | | | | |
| 900V | 16-60mΩ | | | | |
| 1200V | 28-960mΩ | | | | |

# Recommended Products

| Suggested Block | Part Number | Description |
|---|---|---|
| **AC-DC Rectifier** | | |
| Si Rectifiers | ISL9R1560P_F085 | 600V, 15A, 1.65V, TO-220 (2-lead) Stealth™ Rectifier |
| | ISL9R3060G_F085 | 600V, 30A, 2.0V, TO-247 (2-lead) Stealth™ Rectifier |
| | RURG5060_F085 | 600V, 50A, 1.28V, TO-247 (2-lead) Ultrafast Diode |
| | Application Recommended Si Rectifiers | |
| Silicon Carbide (SiC) Diodes | FFSP3065B | SiC Schottky Diode – EliteSiC, 30 A, 650 V, D1, TO-220-2L |
| | FFSH5065A | SiC Schottky Diode – EliteSiC, 50 A, 650 V, D1, TO-247-2L |
| | NDSH30120C-F155 | SiC Schottky Diode – EliteSiC, 30 A, 1200 V, D3, TO-247-2L |
| | NDSH50120C | SiC Schottky Diode – EliteSiC, 50 A, 1200 V, D3, TO-247-2L |
| | Application Recommended SiC Diode | |
| **Power Factor Correction** | | |
| Power Factor Controller | FAN9672 | Continuous Conduction mode PFC, Interleaved Two-Channel |
| | FAN9673 | Continuous Conduction mode, PFC, Interleaved Three-Channel |
| | NCP1680 | Totem-Pole Critical Conduction Mode (CrM) PFC Controller, up to 350W |
| | NCP1681 | Totem-Pole Continuous Conduction Mode (CCM) / Multi-mode (CrM-CCM) Power Factor Correction Controller, up to 3kW |
| Intelligent Power Module PFC Combo | NFCS1060L3TT | Intelligent Power Module (IPM), PFC Combo, 600V, 10A |
| | NFP36060L42T | SPM® 3 27 Series Intelligent Power Module, Bridgeless PFC, 600 V, 60 A |
| | NFL25065L4BT | PFC SPM® 2 Series for 2-Phase Interleaved PFC |
| High Voltage MOSFETs | NTHL017N60S5H | N-Channel, SUPERFET® V, FAST, 600 V, 75 A, 17.9 mΩ, TO-247 |
| | NTP125N60S5H | N-Channel, SUPERFET® V, FAST, 600 V, 22 A, 125 mΩ, TO-220 |
| | NTP185N60S5H | N-Channel, SUPERFET® V, FAST, 600 V, 15 A, 185 mΩ, TO-220 |
| | Application Recommended HV MOSFET | |
| Silicon Carbide (SiC) MOSFETs | NTH4L075N065SC1 | SiC MOSFET - EliteSiC, 57 mΩ, 650 V, M2, TO-247-4L |
| | NTHL023N065M3S | SiC MOSFET - EliteSiC, 23 mΩ, 650 V, M3S, TO-247-3L |
| | NTBG070N120M3S | SiC MOSFET - EliteSiC, 65 mΩ, 1200 V, M3S, D2PAK-7L |
| | NTHL040N120M3S | SiC MOSFET - EliteSiC, 40 mΩ, 1200 V, M3S, TO-247-3L |
| | Application Recommended SiC MOSFET | |
| IGBT | FGH40T65SQD | IGBT, 650 V, 40 A Field Stop Trench |
| | FGA60N65SMD | IGBT, 650V, 60A, Field Stop |
| | FGHL40T120SWD | 1200V, 40A Field Stop VII (FS7) Discrete IGBT, TO247-3L |
| | Application Recommended IGBT | |

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# Recommended Products

| Suggested Block | Part Number | Description |
|---|---|---|
| **Power Factor Correction** | | |
| **Si Rectifiers** | MUR1560 | Power Rectifier, Ultra-Fast Recovery, Switch-mode, 15 A, 600 V |
| | RURG5060-F085 | 600V, 50A, 1.28V, TO-247 (2-lead) Ultrafast Diode |
| | Application Recommended Si Diode | |
| **Silicon Carbide (SiC) Diodes** | FFSP0665B | SiC Schottky Diode – EliteSiC, 6 A, 650 V, D2, TO-220-2L |
| | NDSH50120C | EliteSiC, 50 A, 1200 V, D3, TO-247-2L |
| | Application Recommended SiC Diode | |
| **Inverter Stage** | | |
| **Intelligent Power Modules** | FNB35060T | Intelligent Power Module, 600 V, 50A |
| | NFAM5065L4B | Intelligent Power Module (IPM), 650V, 50A |
| | NFAM3512L7B | Intelligent Power Module, SPM31, 1200V, 35A |
| | NFA32512L72 | Intelligent Power Module, 1200V, 25A |
| | Application Recommended IPM | |
| **Silicon Carbide (SiC) Modules** | NXH010P120M3F1PTG | EliteSiC, 10 mΩ SiC M3S, 1200 V, Half Bridge, F1 Package |
| | NXH010P90MNF1 | SiC Module, 2-PACK Half Bridge, 900 V, 10 mΩ SiC M2 MOSFET |
| | NXH006P120M3F2PTHG | EliteSiC, 6 mΩ SiC M3S, 1200 V, Half Bridge, F2 Package |
| | Application Recommended SiC Power Module | |
| **Silicon Carbide (SiC) MOSFETs** | NTH4L023N065M3S | EliteSiC MOSFET, 23 mΩ, 650 V, M3S, TO-247-4L |
| | NTH4L014N120M3P | EliteSiC MOSFET, 14mΩ, 1200V, M3P, TO-247-4L |
| | NTBG014N120M3P | EliteSiC, 14mΩ, 1200 V, M3P, D2PAK-7L |
| | Application Recommended SiC MOSFET | |
| **IGBT** | FGY100T120RWD | 1200V, 100A Trench Field Stop VII (FS7) Discrete IGBT |
| | FGHL40T120RWD | 1200V, 40A Trench Field Stop VII (FS7) Discrete IGBT |
| | FGHL60T120RWD | 1200V, 60A Trench Field Stop VII (FS7) Discrete IGBT |
| | FGH75T65SHDT | IGBT, 650 V, 75 A Field Stop Trench |
| | Application Recommended IGBT | |
| **IGBT Power Module** | NXH800H120L7QDSG | Qdual3 1200 V 800 A Half Bridge IGBT Module |
| | SNXH800H120L7QDSG | Qdual3 1200 V 800 A Half Bridge IGBT Module for CAV |
| **Stepper Driver** | | |
| **Motor Drivers, Stepper** | NCV70514 | Micro-stepping Motor Driver, dual H-bridge, 800mA, SPI |
| | NCV70517 | Micro-stepping Motor Driver, dual H-bridge, 800mA, SPI |
| | NCV70628 | LIN Micro-Stepping Motor Driver 800mA |

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# Recommended Products

| Suggested Block | Part Number | Description |
|---|---|---|
| **Gate Driver** | | |
| **Three Phase Gate Driver** | NCD83591 | 3-phase, 60V gate driver for motor control applications |
| | FAN73893 | 3-Phase Half Bridge Gate Drive IC |
| | FAN7888 | 225V, 3.3/5V input logic compatible, 0.65/0.35A sink/source current |
| | FAN7388 | 625V, 3.3/5V input logic compatible, 0.65/0.35A sink/source |
| **Half Bridge Si Gate Driver** | NCP5104 | Single Input High and Low Side Power MOSFET Driver |
| | NCP5106 | MOSFET / IGBT Drivers, High Voltage, High and Low Side |
| | NCP5111 | Power MOSFET / IGBT Driver, Single Input, Half-Bridge |
| | NCD57252 | Isolated Dual-Channel IGBT Gate Driver |
| | Application Recommended Si/IGBT Half Bridge Gate Driver | |
| **Single Channel Gate Driver** | NCP51313 | High Side Gate Driver, 130 V, 2.0 A / 3.0 A |
| | FAN73711 | 625V,3.3/5V input logic compatible 4/4A sink/source current, High Side |
| **Half Bridge Isolated SiC Gate Driver** | NCP51563 | 5 kVRMS Isolated Dual Channel 4.5/9 A Gate Driver with High Channel-to-Channel Spacing |
| | NCP51561 | 5 kVrms Isolated Dual Channel 4.5/9 A Gate Driver |
| | NCP51560 | 5 kVrms Isolated Dual Channel 4.5/9 A Gate Driver |
| | NCD57540 | Isolated Dual-Channel Gate Driver with >8mm Creepage and Clearance |
| **Single Isolated SiC Gate Driver** | NCD57090 | Isolated High Current Gate Driver |
| | NCD57000 | Isolated high current and high gate driver with internal galvanic isolation |
| | NCD57001 | |
| | NCP51752 | 3.75 kVRMS, 4.5-A/9-A Isolated Single Channel Gate Driver with Integrated Negative Bias Control |
| | NCP51152 | 3.75 kVRMS, 4.5-A/9-A Isolated Single Channel Gate Driver |
| **LLC Converter** | | |
| **LLC Controller** | NCP4390 | Resonant Controller with Sync. Rectifier Control, Enhanced Light Load |
| | NCP13992 | Current Mode Resonant Controller with Integrated High Voltage Drivers |
| | NCP13994 | Current Mode Resonant Controller, Active X2 |
| | Application Recommended LLC Controller | |
| | NCP4305 | Sync. Rectification Driver for QR, Forward & LLC |
| | NCP4306 | Sync. Rectification Driver for QR, Forward & LLC |
| | NCP4307 | SR Driver with Dual Vcc and Self-supply for ACF, QR, Forward & LLC |
| | Application Recommended SR Controller | |

# Complementary Products

| Suggested Block | Part Number | Description |
|---|---|---|
| **ADC & Isolation** | | |
| ADC | NCD98011 | 12-Bit Low Power SAR ADC Signed Output |
| | NCD98010 | 12-Bit Low Power SAR ADC Unsigned Output |
| Digital Isolation | NCID9411 | High Speed Quad-Channel Digital Isolator |
| | NCID9401 | High Speed Quad-Channel Digital Isolator |
| | NCID9211 | High Speed Dual-Channel, Bi-Directional Ceramic Digital Isolator |
| **Auxiliary Power Supply** | | |
| Controllers | FAN65008B | Synchronous Buck Regulator, 65V, 10A |
| | FAN65004B | Synchronous Buck Regulator, 65V, 6A |
| Offline Controllers | NCP1077 | High Voltage Switching Regulator for Offline SMPS |
| | NCP1253 | PWM Controller, Current Mode, for Offline Power Supplies |
| | NCP1568 | AC-DC Active Clamp Flyback PWM Controller |
| | NCP1239 | Fixed Frequency Current Mode Controller for Flyback Converter |
| | Application Recommended Isolated SMPS | |
| LDO | NCP189 | LDO, 500mA, Low noise, High Accuracy with Power-Good |
| | NCP164 | LDO, 300mA, Ultra-Low Noise, High PSRR with Power-Good |
| | NCP718 | LDO Regulator, 300 mA, Wide Vin, Ultra-Low Iq |
| | NCP730 | LDO Regulator, 150 mA, 38 V, 1 uA IQ, with Power-Good |
| | Application Recommended LDO | |
| eFuse | NIS3071 | Electronic fuse 4-channel, 8V to 60V, 10A in 5x6mm package |
| | NIS4461 | Electronic fuse (eFuse), 24V, 44mΩ, 4.2A |
| **Interface** | | |
| CAN/CAN FD | NCV7344 | CAN FD Transceiver, High Speed, Low Power |
| | NCV7351 | CAN/CAN FD Transceiver, High Speed |
| | NCV7357 | CAN FD Transceiver, High Speed |
| ESD Protection | NUP3125 | 32V Dual Line CAN Bus Protector in SC-70 (SOT-323) |
| | NUP3105L | 32V Dual Line CAN Bus Protector in SOT-23 |
| | ESD7004 | ESD Protection Diode with Low Capacitance |
| | ESD7504 | ESD Protection, USB3.0 ESD Protection Array |
| | ESD7205 | Low Capacitance ESD Protection Diodes for High Speed Data Lines |
| Ethernet Controllers | NCN26010 | Ethernet Controller, 10 Mb/s, Single-Pair, MAC + PHY, 802.3cg, 10BASE−T1S Compliant |
| | NCN26000 | 10BASE-T1S Ethernet PHY with MII interface |

# Complementary Products

| Suggested Block | Part Number | Description |
|---|---|---|
| **Memory** | | |
| **EEPROM** | CAT24C04 | EEPROM Serial 4-Kb I2C |
| | CAT24C128 | EEPROM Serial 128-Kb I2C |
| | CAT24M01 | EEPROM Serial 1-Mb I2C |
| | CAT25080 | EEPROM Serial 8-Kb SPI |
| | CAT25640 | EEPROM Serial 64-Kb SPI |
| | CAT25M01 | EEPROM Serial 1-Mb SPI |
| **Flash Memory** | LE25U20AMB | Serial Flash Memory, 2 Mb (256k x 8) |
| | LE25U40CMC | Serial Flash Memory, 4 Mb (512K x 8) |
| | LE25S161 | Serial Flash Memory, 16 Mb (2048K x 8) |
| **SRAM** | N01S818HA | Serial SRAM Memory, Ultra-Low-Power, 1 Mb, 1.7 - 2.2 V |
| | N25S818HA | Serial SRAM Memory, 256-kb, 1.8 V |
| | N64S830HA | Serial SRAM Memory, 64-kb, 3.0 V |
| **Current & Voltage Sense** | | |
| **Current Sense Amplifier** | NCS21673 NCS21674 | Current-Shunt Monitors, 40 V Common Mode, Uni-directional, Single/Dual |
| | NCS21671 | Current-Shunt Monitors, Zero-Drift, 40 V Common Mode, Bi-directional, Shutdown |
| | NCS7030 NCS7031 | Current-Shunt Monitors, 80 V Common Mode, Uni-directional |
| | NCS7041 | Current-Shunt Monitors, 80 V Common Mode, Bi-directional |
| | NCS210R NCS211R NCS213R NCS214R | Current Sense Amplifier, 26V, Low-/High-Side Voltage Out, Bidirectional Current Shunt Monitor |
| **Voltage Sense** | NCS2003 | Operational Amplifier, High Slew Rate, Low Voltage, Rail-to-Rail Output |
| | NCS21801 | Operational Amplifier, 10µV, Zero-Drift, 1.8V to 5.5V Supply, 1.5 MHz |
| | NCS21914 | Precision Quad Operational Amplifier, 2 MHz Bandwidth, Low Noise, Zero-Drift, 25 µV Offset |
| | Application Recommended Voltage Sense Amplifier | |
| **Inductive Sensing** | | |
| **Inductive Sensor** | NCS32100 | Industrial Rotary Position Sensor – 6000 RPM full accuracy, 50 arcsec accuracy |
| | NCV77320 | Inductive Position Sensor Interface, linear and angular, SPI |
| **Temperature Sensing** | | |
| **Temperature Sensor** | NCT72 | ±1°C Temperature Monitor with Series Resistance Cancellation |
| | N34TS108 | Low-voltage Digital Temperature Sensor |
| | NCT375 | Digital Temperature Sensor with 2-wire Interface and SMBus Time-Out |

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# Technical Documentation

| Name | Description and Link |
| --- | --- |
| Whitepaper | DC Motor Driver Fundamentals |
| Webinar | How to optimize your industrial drives and pumps |
| Whitepaper | Stepping Motors and Stepping Motor Control System |
| Whitepaper | Trapezoidal Control of BLDC Motors |
| Whitepaper | Advanced Industrial Motor Control for Increased Power Efficiency |
| Whitepaper | Sensorless Direct Torque and Flux Control with Permanent Magnet Synchronous Motors |
| Application Note | 3-phase Inverter Power Module 1200 V SPM 31 Version 2 Series Application Note |
| Application Note | onsemi M 1 1200 V SiC MOSFETs & Modules: Characteristics and Driving Recommendations |
| Application Note | 3-phase Inverter Power Module 650 V SPM 49 Series Application Note |
| Application Note | Smart Power Module, Motion SPM 45 V3 Series User's Guide |
| Application Note | Paralleling of IGBTs |
| Application Note | MOSFET Basic |
| Application Note | IGBT Basic II |
| Application Note | Effect of Gate-Emitter Voltage on Turn on Losses and Short Circuit Capability |
| Evaluation Kit | 4kW 650V Industrial Motor Control Development Kit with Intelligent Power Module (IPM) and Universal Controller Board (UCB) |

# Technical Documentation

| Name | Description and Link |
| --- | --- |
| Application Note | Practical Design Guidelines on the Usage of an Isolated Gate Driver |
| Application Note | A Guideline on the Usage of an Isolated Gate Driver to Efficiently Drive SiC MOSFETs |
| Whitepaper | SiC MOSFETs: Gate Drive Optimization |
| Application Note | Active Miller Clamp Technology |
| Blog | Choosing the Right Silicon Carbide Gate Driver |
| Evaluation Board | NCD83591 60V, 3-Phase Gate Driver Demo Board |
| Tutorial | Elite Power Simulator User Guide |
| Application Note | Technical Advantages of onsemi's New Elite Power Simulator and Self-Service PLECS Model Generator |

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