Combining Inrush Current Limiting with PFC for White Goods Motor Applications

Devices that execute multiple application functions to reduce system complexities

When Europe mandated the requirement that electric loads of 80W or above draw current in a high power factor manner, it was another incremental step towards conservation and a greener environment.

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Many of the consumer products affected include white goods appliances. Many of these appliances such as air conditioners, refrigerators, washers and dryers have complex loads due to the inverter for the electric motor drive. In principle, complex loads generally have poor power factors. By mandating that theses appliances be power factor corrected (PFC) the transmission lines power delivery is better utilized, saving energy and reducing both the cost of electricity and the release of carbon emissions from the burning of fossil fuels. Around the world today, many government regulatory agencies have mandated similar requirements for PFC in these applications.

The front end of a motor drive circuit without PFC looks very similar to a switch mode power supply where bulk storage capacitance resides that smoothes out the DC from the rectified mains. When initially energizing the motor drive circuit, the mains input looks essentially like a short circuit because there is no charge on the bulk capacitors. When power is applied this condition results in high inrush currents to charge the capacitor. If this inrush current is not controlled or limited, the

current draw from the line will surge to magnitudes higher than its normal RMS operating current (Figure1). These excessive currents potentially can damage or stress both mechanical and electrical elements such as fuses, solder joints or electronic components, just to name a few.

Most white goods motor manufacturers have adopted the use of a negative temperature coefficient resistor (NTC) to limit inrush current. The NTC operation is very simple. Under cold or initial start up conditions the NTC is a high resistance device and limits the current quite well. After start-up or a few moments into normal operating conditions, the

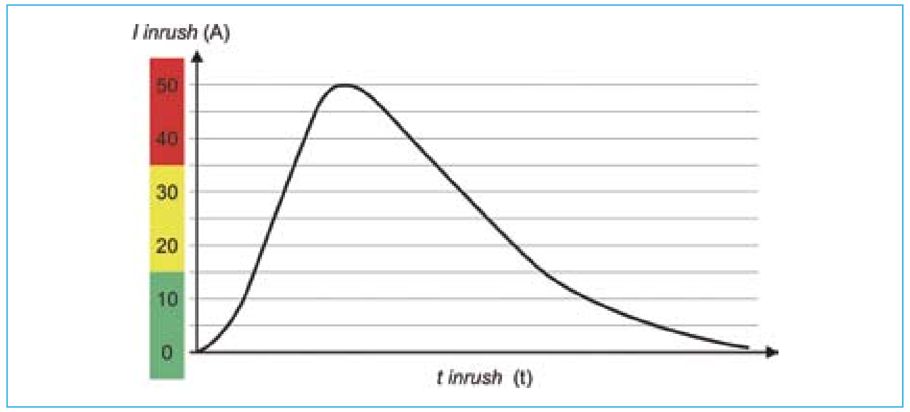

Figure 1: Typical 120VAC inrush current plot.

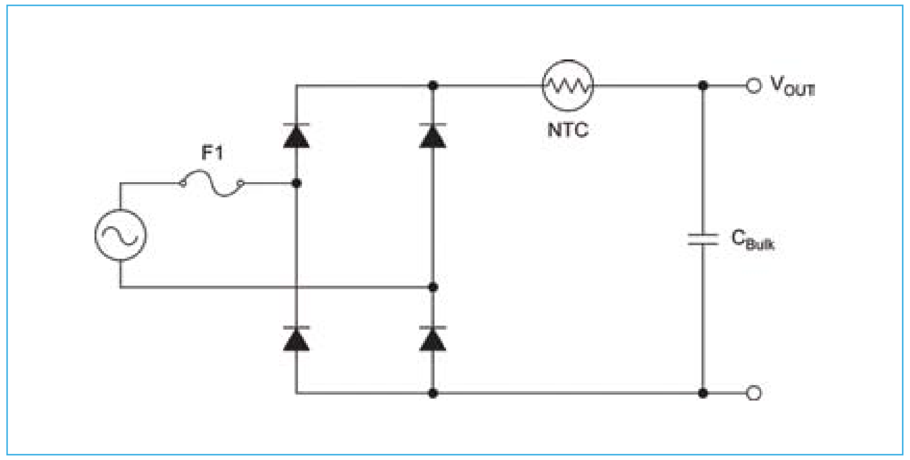

Figure 2: Typical inrush protection circuit.

NTC gets warmer due to power dissipation. As it gets warmer its resistance significantly decreases, making it a more efficient path for current to flow through. In most embedded motor drive circuits the NTC is placed somewhere in the high current path, either on the AC side or just after the bridge rectifier (See Figure 2).

There are some inherent shortfalls with the NTC approach that can adversely affect the embedded motor's drive reliability. As previously mentioned, the NTC's efficiency depends on the temperature. The hotter it becomes, the more efficient it is. An NTC cannot be heatsinked to conduct the heat away; otherwise it will not work as intended. This dissipation is left to heat the surrounding environment where the other semiconductor components reside. In the embedded environment the problem is exacerbated. An increase of just 10oC can reduce the semiconductors expected life or mean time between failures (MTBF) by as much as half, significantly reducing the drive's reliability.

Another major problem with the NTC is its thermal mass or time response. A problem could arise if the mains voltage were to momentarily dropout or severely brownout for a period just long enough where significant charge is depleted from the bulk capacitors. When the line voltage recovers, the NTC may not have had enough time to cool down, and is in its low resistance state. The inrush currents associated with the line recovery in this event allow even higher surge currents than normally present, even higher than those at initial start up. In this case there is no protection. These unusually high currents could damage power train elements such as fuses, solder joints, traces or all the elements in the path.

Figure 3 show an implementation that overcomes many of the undesirable problems of the NTC. This alternative method can use either a fixed value resistor or an NTC as the inrush resistor. The inrush circuit described here has two additional silicon controlled rectifiers (SCRs) and an unregulated voltage source from a small auxiliary winding from the PFC boost inductor.

During initial powering up of the motor circuit, current flows through the bridge rectifier through the inrush resistor, to the bulk capacitors where the current is limited by the inrush resistor. After some time, usually determined by the PFC controller circuit, it starts its operation. When it starts, the PFC controller starts switching the power MOSFET, which in turn starts pulsing the current in the boost inductor. This pulsing current then produces a floating unregulated voltage on the auxiliary winding that is used to trigger the gates of the two SCRs. The two SCRs are placed in the circuit in such a way as to provide a current path that bypasses two of the rectifiers in the bridge along with the inrush resistor. This alternative path provides a very efficient path for the current without an additional series element being added to the circuit. Even though SCRs have a slightly higher forward voltage drop (Vf) than the rectifier diodes, the voltage drop across the current limiting element, such as a fixed resistor or NTC, has been eliminated. Furthermore, the heat dissipated from the SCRs can be removed by heat-sinking to the chassis; an impossibility with the NTC. This heat removal capability can result in cooler operation resulting in higher system reliability or MTBF figures.

The turn ratio of the auxiliary winding must be selected to ensure that enough voltage is produced to trigger the gates of the SCRs under all specified line voltage limits. The timing of the gate triggering is usually inconsequential because the switching frequency of the PFC circuit is typically much greater that the line frequency. A PFC circuit running at a mere 40 kHz will most definitely ensure SCR zero crossing switching, making them act much like the simple rectifiers in the bridge.

Figure 3 shows a simplified schematic of the industries first single chip dual-phase interleaved PFC pre-regulator, the UCC28070 from Texas Instruments. Interleaving two phases 180o apart provides ripple current cancellation. This enables the use of a smaller electro-

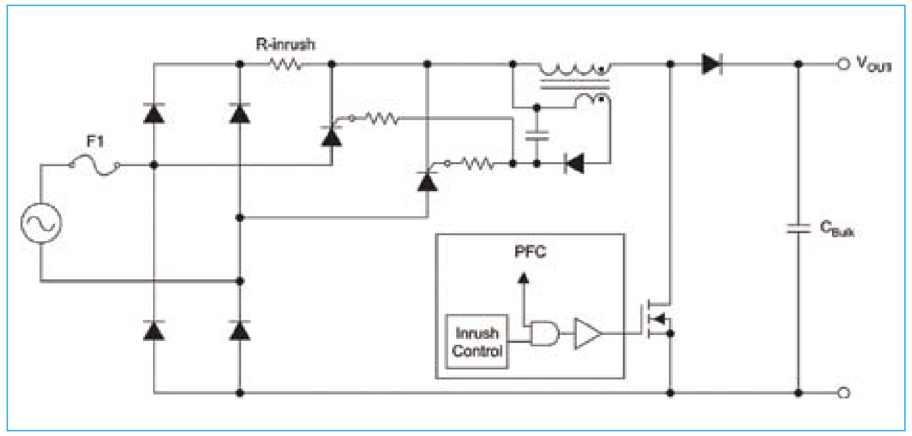

Figure 3: Inrush control function in PFC controller.

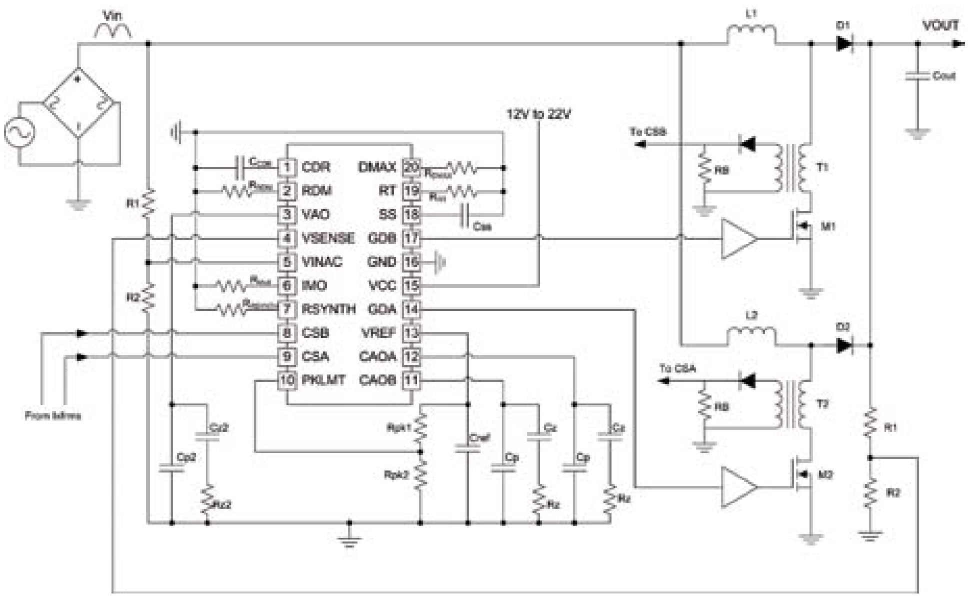

Figure 4: UCC28070 two-phase interleaved PFC.

magnetic interference (EMI) filter along with physically smaller PFC output capacitors. These smaller elements of the dual-phase interleaved topology make it an ideal solution for embedded motor drive circuit. An interleaved PFC can meet very high power density requirements including low height.

Other benefits of interleaving include easier thermal management since power dissipation is distributed over two phases. Reduced overall system cost from a smaller EMI filter, smaller PFC output capacitor sizes, and less magnetic material as the total inductor volume of the two phases are significantly smaller than a single stage design (Figure 4). Also, the MOSFET and diode current ratings can be reduced by at least 50 percent. Smaller MOSFETs are inherently faster, which further reduces MOSFET switching losses. Finally, the economy of scales increases the buying power on matching devices in each phase by doubling the volume of each.

The UCC28070 works in continuous conduction mode (CCM). Also available is the UCC28060 which is a transition mode (TM). The UCC28060 has similar benefits afforded with ripple current cancellation, but also offers some lower cost alternatives. Most notably is the use of low cost boost diodes since there is no reverse recovery condition in transition mode operation.

To incorporate inrush in the UCC28070 or its design, simply add the inrush components from Figure 3 to either of the phase inductors.

Texas Instruments PFC controller roadmaps include devices such as the UCC28070 or UCC28060 interleaved PFC controllers that have an additional functional block. This additional block monitors both the input and output sides of the PFC controller. If it determines that an inrush condition exists, such as a momentary loss in line voltage, it will override the gate drive output, stopping the MOSFET from switching and shutting down the power in the SCRs gate drive circuit. This will naturally engage the inrush element back into the high current path.

A final note

When it comes to system integration for white goods applications, many designers favor alternative paths. Some prefer to go the route of devices that can execute multiple application functions to reduce system complexities and enable faster time-to-market. For example, the C2000 digital signal controllers (DSC) from TI can replace the microcontroller traditionally used for motion control while adding advanced motor control algorithms such as field-oriented control. It improves efficiency while using smaller power electronics. Besides being adaptable to various PFC topologies including interleaving, C2000 DSCs can simultaneously implement all the necessary three-phase motor control functions, handle in-system communications, provide for a user interface, and also provide the inrush current limiting control described, all in a single C2000 digital signal processor (DSP).

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