ON Semiconductor

Is Now

To learn more about onsemi™, please visit our website at www.onsemi.com

AND9172/D

Pre-Regulator for High Voltage Supply

ON Semiconductor®

http://onsemi.com

APPLICATION NOTE

INTRODUCTION

To allow worldwide use, most of today consumer products are developed with a power supply capable of operation on both 110 V and 230 V mains inputs: Switch Mode Power Supply's (SMPS) designers are used to developing so-called wide-range/universal mains SMPS (from 90 to 264 V rms) connected between phase and neutral of the mains distribution.

Despite a universal mains design, some products are now requested to support a much higher input voltage corresponding to a fault condition: open neutral or an accidental two-phase connection in a 3-phase network.

The first request came up for E-metering products to support a wrong connection on the 3-phase distribution network (even for domestic single-phase installation).

The second request concerns the auxiliary power supply built in high power white good products supplied from a 3-phase input (air condition or induction cooking).

If for dedicated US design we are able to cope with a classical universal mains SMPS, for Europe (EU) and Asia (230 V rms) this new request asks for a specific design capable to operate up to 460 V rms (> 600 V dc after rectification).

After a short review of existing solutions supporting extra wide-voltage, this document will explain the new solution proposed by ON Semiconductor based on the switching pre-regulator converter.

This pre-regulator is a specific function added to a conventional SMPS and is inserted between the ac supply rectification and the input bulk capacitor supplying the downstream converter. This pre-regulator allows for an upper input range, from a mains input exceeding 460 V rms without a) the drawback of the series arrangement of two bulk capacitors and b) a high supply voltage for the flyback converter (built with a cascode arrangement or a very high voltage MOSFET transistor).

The pre-regulator is working like a Low Drop-Out (LDO) regulator, providing around 200 V dc regulated voltage, but its switching behavior avoids excessive power dissipation, large heat sink and reliability issues.

If the solution can be used with any type of SMPS, the limited power considered here makes the new NCP1075SOTGEVB evaluation board (configured for 12 V output) the topology of choice for that type of applications. The architecture is patented by ON Semiconductor but a royalty free license is available when using the ON Semiconductor SMPS solution.

The switching topology is a discontinuous mode flyback converter built around the ON Semiconductor NCP1075 monolithic switcher. The specific default evaluation board features an output rating of 12 V at 1 A maximum.

The insertion of the pre-regulator asks for some modifications of the original NCP1075SOTGEVB that will be explained later-on.

May, 2014 - Rev. 0

Publication Order Number:
AND9172/D

AC SUPPLY CONFIGURATIONS & HIGH VOLTAGE SUPPLY

Below is an overview of possible ac configurations and corresponding failures and issues for 230 V rms supply, for multiple and single-phase inputs, for full-wave and half-wave rectification.

This table provides the best possible pre-regulator solution when applicable. If most configurations can work with a 200 V pre-regulator, some of them will ask for a 350 V output and limited number (mainly 3 phases) cannot be supported.

Table 1. SUMMARY OF ALL POSSIBLE AC CONFIGURATIONS

SMPS AC Line Connections	Bridge Rectification	VDC	Pre-Regulator Output (V)	Output Bulk Capacitor	Results
3-phase	Full-wave	620	N/A	2 x 400 V min	Cascode approach
	Half-wave	330	350 V	1 x 400 V	OK
3-phase with only 2 connected	Full-wave	620	350 V	1 x 400 V	OK
3-phase w/o Neutral	Full-wave	620	N/A	2 x 400 V min	Cascode approach
	Half-wave	0	N/A	N/A	No DC supply available
3-phase with Neutral connected to 1 phase	Full-wave	620	350 V	1 x 400 V	OK
	Half-wave	610	200 V	1 x 250 V	OK
Single phase	Full-wave	330	200 V	1 x 250 V	OK
	Half-wave	330	200 V	1 x 250 V	OK
Single phase with Neutral connected to 2nd phase	Full-wave	620	200 V	1 x 250 V	OK
	Half-wave	620	200 V	1 x 250 V	OK

EXISTING HIGH-VOLTAGE INPUT CONVERTERS SOLUTIONS OVERVIEW

Solutions are currently available, based on classical SMPS modified to support higher supply input voltages. The first modification is related to the input bulk capacitor: two of them are connected in series to support more than 600 V as 450 V is the maximum value available on the market. As capacitors are in series, their value should also be doubled to keep the same overall energy stored for hold-up time.

To avoid an unbalanced voltage spread between capacitors, resistances (with added consumption) should be connected in parallel with each capacitor as well as Transient Voltage Suppressor (TVS) to protect against shorted capacitors tests.

The second modification is related to the switching element maximum voltage rating used in the SMPS. Two solutions are popular in the market.

1000 V MOSFET + PWM Controller

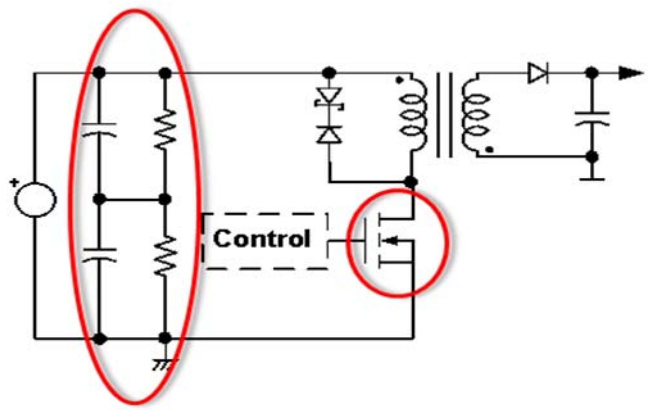

Figure 1. 1000 V MOS + PWM Controller

If this solution uses a classical type of design and thus avoids an added switching block, the SMPS should be designed for a wide range input with corresponding wide frequency dynamics or t_{on} variations to maintain regulation across the input range. The high dV/dt will increase switching losses, affecting efficiency with important risks of interferences (EMI). An expensive 1000 V (or more) MOSFET has to be used to support the transformer flyback voltage on top of the high-input voltage.

Cascode with a 700 V Switcher

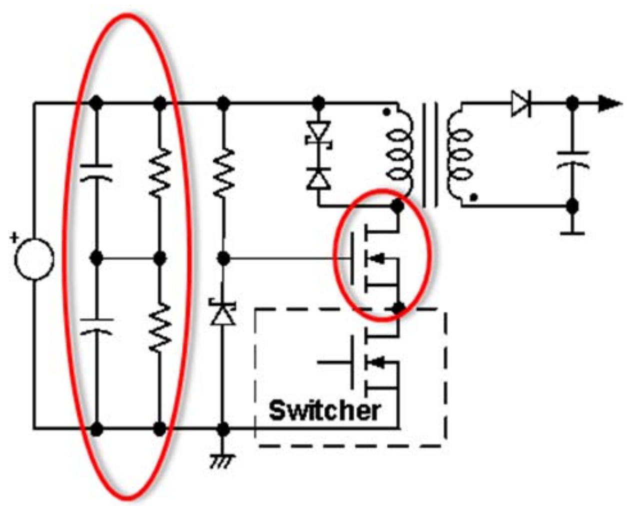

Figure 2. Cascode with a 700 V Switcher

If this solution uses a standard type of switcher, an extra power MOSFET should be implemented to sustain the flyback voltage added to the rectified input voltage. This simple circuit asks for a limited control change, done with added TVS supplied from input supply. This type of solution allows voltage sharing between 700 V switcher and 600 V Power MOS.

The SMPS should also be designed for a wide range input voltage with a corresponding large switching frequency excursion or t_{on} dynamics to ensure a correct output voltage regulation. Switching losses budget is similar and affects efficiency with risk of a complex EMI signature.

800 V Power MOSFET or Integrated Switchers

To avoid specific design, some applications may use classical Wide Range solution with 800 V Power MOS or integrated switcher despite this asks for very critical design:

- The reflected voltage from the transformer should be very low to keep the MOS maximum voltage below 800 V despite the high supply voltage (~620 V). This will ask for low turns ratio Np / Ns, low primary inductance with extremely short Power MOS's t-on, long conduction time for secondary diode with very high reversed voltage and direct impact on Vf and efficiency.
- The pick voltage related to transformer's leakage inductance (added to reflected voltage) should be kept very low as well to stay below the 800 V limit. This will ask for larger snubber with higher power dissipation and direct impact on overall efficiency.

If 800 V switcher looks to be possible, the overall design constraints will make the design very critical, with limited performances, higher reliability risks and added cost:

- The very short t-on by high mains supply and low output power may create regulation instability and force the SMPS to work down to low frequency if not burst mode.
- 10% of voltage margin is usually considered for avalanche proof Power MOS but 20% should be considered for non avalanche proof ICs to avoid any reliability issues during transients and start-up phase.
- Larger secondary reversed voltage diodes will impact the efficiency and cost with larger packaging to support the higher Vf and power dissipation.

NEW ON SEMICONDUCTOR 200 V PRE-REGULATOR

Principle

Add a voltage regulator between mains and SMPS to avoid Bulk input capacitor and Power Supply to support the high voltage supply.

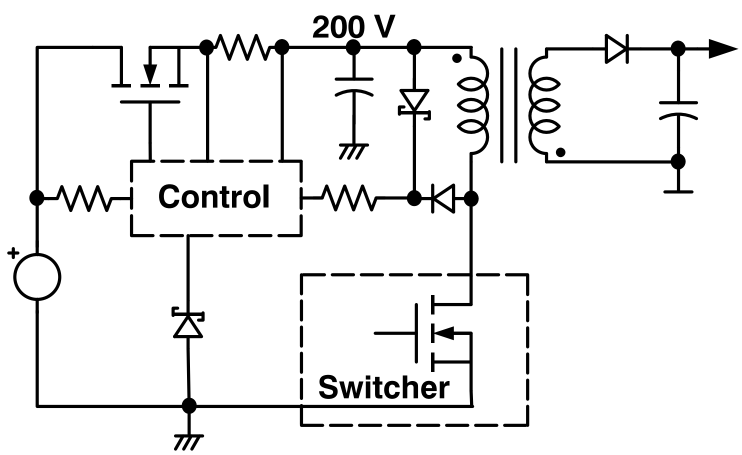

Figure 3. 200 V Pre-Regulator with Switcher

After ac mains voltage rectification, an added regulator is used to supply the bulk capacitor.

- This pre-regulator could be set just to avoid input supply to go over the normal 380 Vdc, allowing single standard 450 V capacitor and 700 V integrated switcher without voltage and design issues.
- To avoid "wide range" of bulk voltage supply, the regulated voltage can be adjusted down to the corresponding min supply voltage (140 Vac x ~200 Vdc) allowing reduced voltage bulk capacitor down to 250 V type (reduced size and cost).
- To be able to use better and lower cost N-MOS, the SMPS's snubber, providing higher voltage than bulk capacitor, is used to control and drive the Pre-regulator's N-MOS.
- To improve efficiency (~90%), the switching pre-regulator should be synchronized on mains supply to provide energy to the bulk capacitor with minimum voltage drop through the Power MOS.

- Half wave mains rectification is preferred than full wave to avoid too short on-time and reduce switching losses (improving efficiency with large bulk capacitor).
- To avoid safety issues, the pre-regulator should have an embedded current limitation which will act as Inrush limiter during the start-up phase (avoiding external one).

Thanks to the added pre-regulator, the design of the post SMPS will be simplified.

- The lower and regulated bulk voltage supply will simplify the SMPS design, avoiding “wide range” supply with corresponding large frequency and t-on variation.
- Hold up time done with smaller 250 V bulk capacitor can be easily improved with limited size and cost impact (250 V type are much smaller and cheaper than double values 450 V).
- This will provide higher transformer design flexibility with larger reflected voltage capability (thanks to reduced supply voltage)
  - Improving efficiency with reduced snubber’s size and dissipation.
  - Allowing reduced reversed voltage (lower Vf) for secondary diode
- The reduced supply voltage will improve both switching losses and EMI.
- This will overall improve SMPS efficiency, reducing strongly both size and cost.

Impact and Modifications on Existing SMPS to use ON Semiconductor’ Pre-Regulator

As this type of pre-regulator solution should be considered for power below 30 W, we will consider only Flyback topology.

If any applications could be modified to get the full benefit of this pre-regulator solution, the ON Semiconductors related patent will limit the field of application to ON Semiconductor SMPS switchers or controllers.

Mains filter does not ask for modification as the current will not exceed the current delivered by min supply voltage with classical solution. The Inrush limiter (resistance of NTC) can be removed as it is performed by the pre-regulator current limitation.

Bridge or rectification should be removed from the SMPS as half wave rectification (single diode) is inserted on pre-regulator evaluation board. The Neutral “bridge input” should be directly connected to SMPS GND bulk capacitor.

If on final solution, bulk capacitor could be a single part, it is recommended to share in 2 when both (SMPS and pre-regulator) are on different boards to avoid issues and EMI. The 400 / 450 V SMPS bulk cap can be changed to a reduced voltage type according to Pre-regulator output.

Snubber circuit capacitor can be reduced if the supply voltage (bulk capacitor voltage) is down to lower value. The snubber resistance can be increased accordingly.

4 wires should be soldered to connect both SMPS and pre-regulator together.

- 1 for GND
- 1 for Phase / input voltage
- 1 for bulk capacitor / output voltage
- 1 for snubber voltage used as V-supply to drive pre-regulator’s N-MOS

HIGH VOLTAGE SUPPLY 10 W 12 V POWER CONVERTER

The below SMPS has been developed for Smart or Electric Meters and White Goods applications with the specific pre-regulator supporting Ultra High Voltage Supply up to 460 Vac.

Despite the pre-regulator solution can be used with any existing SMPS, this design is based on existing Universal ac input (90 – 264 Vac), 12 V / 10 W output with Fixed Frequency PWM Isolated Flyback and the new NCP1075 switcher providing high features level and integration.

http://www.onsemi.com/PowerSolutions/vanityUrl.do?requri=/pub_link/Collateral/NCP1072-D.PDF

Fixed Frequency PWM Flyback Power Supply

Based on Design Note – DN05018/D

http://www.onsemi.com/pub_link/Collateral/DN05018-D.PDF

Circuit Description

This design note describes a simple, low power (10W or less), universal ac input, constant voltage power supply where isolation from the mains, low cost and high efficiency are required. The featured power supply is a simple flyback topology utilizing ON Semiconductor’s new NCP1075 SOT-223 monolithic switcher.

The simple input EMI filter is adequate to pass Level B for FCC conducted EMI compliance and the NCP431 plus optocoupler feedback scheme provides for excellent line and load regulation along with high input-to-output isolation. Performance characteristics for efficiency, output ripple, and internal MOSFET drain switching characteristics are shown in the design note. Enhanced input transient protection (lightning, etc.) can be accomplished with the addition of an appropriate TVS device across C2.

Key Features

- Universal AC input range (85 – 300 V rms)
- Input filter (pi-network) for conducted EMI attenuation and input transient protection
- Very low standby power consumption (< 65 mW)
- Frequency foldback under light load and/or over current conditions
- Secondary circuit easily configured for different output voltages
- Inherent over-current, over-voltage and over temperature protection

Circuit Schematic

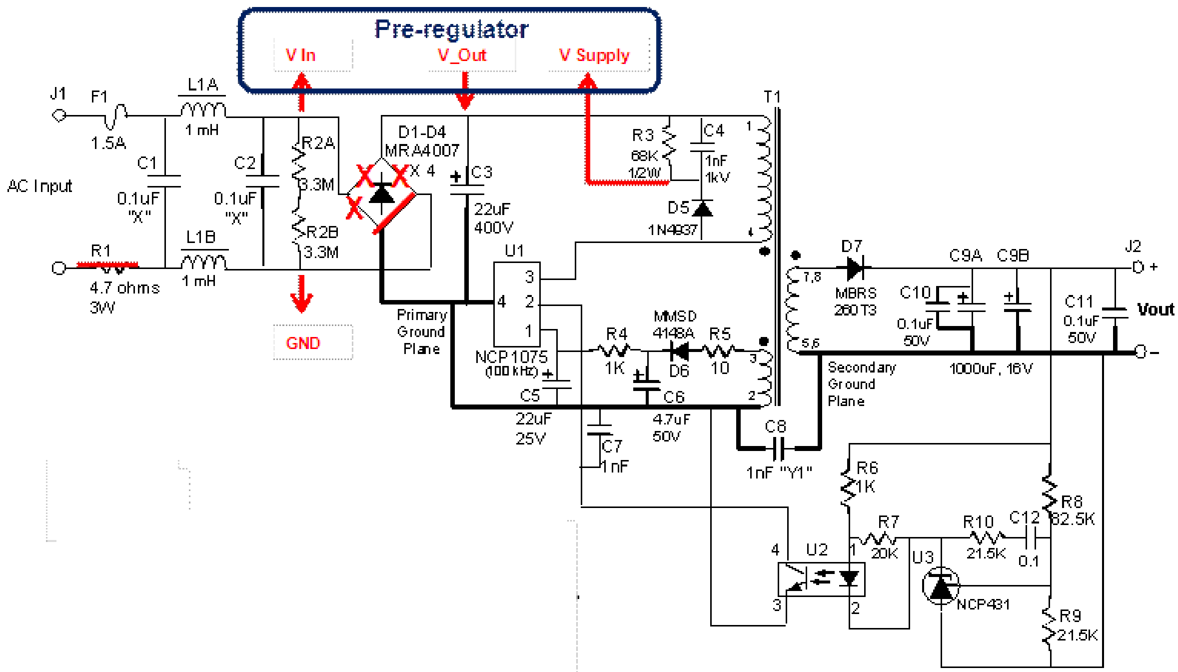

Figure 4. NCP1075 Flyback Schematic and Modifications

Modifications to be connected to Pre-regulator solution

1. Pre-regulator inserted between mains input & bulk cap:
   - D1 – D4 to be removed (single rectification diode on pre-regulator board)
   - D1 to be replaced by jumper to connect GND
2. Inrush limiter R1 (4.7 Ω) to be replaced by jumper (Inrush is embedded in pre-regulator)
3. Snubber capacitor C4 to be changed from 1 nF to 100 pF to reduce snubber effect (particularly in light load conditions) thanks to the reduced bulk supply voltage
4. Snubber resistance R3 to be changed from 68 kΩ to 220 kΩ to reduce power dissipation
5. U1 NCP1075 to be changed from 100 kHz to 130 kHz type to increase power capability (from 10 to 12 W) without switching losses drawback thanks to the reduced bulk supply voltage. This also allows to be (at full load) out of critical frequency range for E-meter communication.
6. Bulk capacitor C3 can be changed from 400 V to 250 V but it is not mandatory for the tests
7. Wires soldered on the board to interconnect GND, Vin, Vout and Vsupply on Pre-regulator

Remarks

A dedicated design should allow further size and cost improvements on transformer, secondary diodes and capacitors, snubber and auxiliary supply.

PWM Flyback behaviors and scope captures

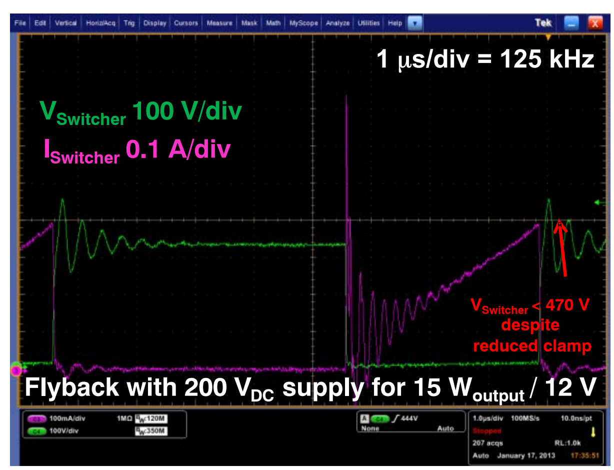

Figure 5. CCM Flyback with 15 W at 12 V

Thanks to the regulated bulk supply, t-on and switching frequency variations are now limited to load variation. Above 10 W of output power, the Flyback is working in Continuous Conduction Mode.

Thanks to the higher switching frequency (up to 130 kHz), the design is capable to provide 12 W without any primary current limitation. Despite reduced snubber and higher power output, we have much larger voltage margin on the switcher (< 470 V provides more than 30% margin of 700 V) thanks to the reduced supply voltage (~200 V compared to 380 V).

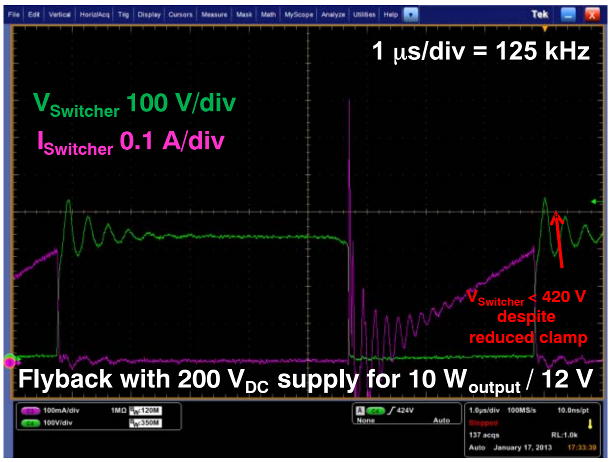

Figure 6. DCM Flyback with 10 W at 12 V

With reduced output power down to 10 W, the Flyback is working in DCM avoiding trapezoidal current waveform and reducing switching losses.

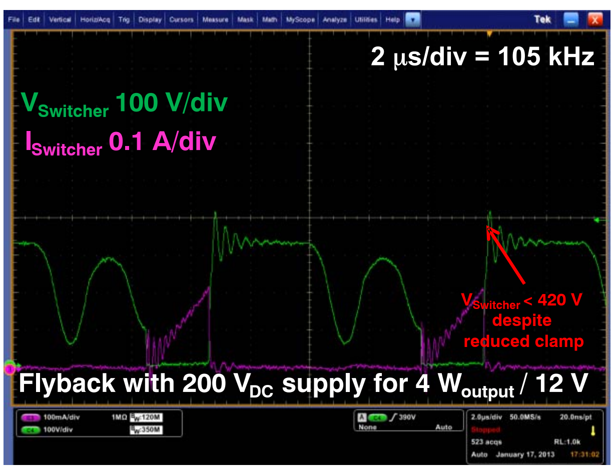

Figure 7. Reduced Switching Frequency for 4 W at 12 V

To avoid too short t-on and to reduce switching losses, thanks to the NCP1075 feature, the switching frequency is reduced with lower output power to keep high efficiency solution.

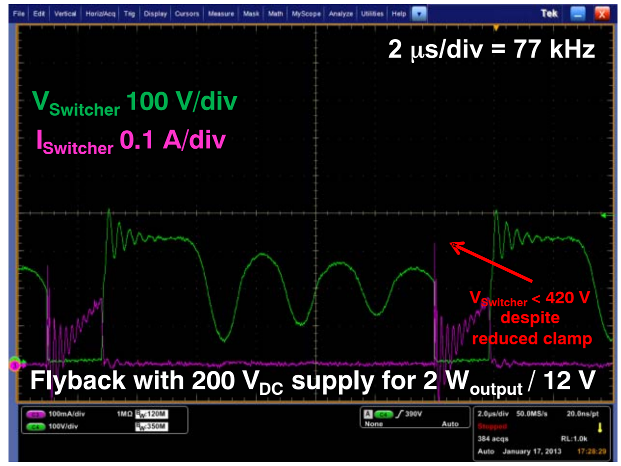

Figure 8. Frequency Foldback with 1 W at 12 V

With further reduced output power, the frequency is going down to 77 kHz to keep the t-on around 2 μs. This solution avoids too early low frequency skip mode and corresponding output ripple.

Advantages of lower and regulated supply voltage for PWM Flyback

Thanks to the lower supply voltage and despite we change to smaller snubber, the voltage on the NCP1075 switcher stays below 470 V. This provides very good design margin (> 33%) when compared to the 700 V Max voltage rating.

The reduced supply voltage will improve the switching behavior with reduced losses even when working in Continuous Conduction Mode (full power 15 W output). This will also improve overall EMI behavior.

Thanks to the regulated voltage, both t-on and switching frequency will not be affected by the ultra wide range of supply voltage. This strongly limits the switching frequency variations that are only affected by output power variations. The built-in frequency foldback will reduce the switching frequency avoiding too short t-on and improving the overall efficiency.

Thanks to the reduced supply voltages, overall rectifier diodes (clamp, auxiliary and secondary) can be changed to lower reversed voltage types, reducing the Vf for better efficiency. This can be further improved when secondary diodes can be changed to Schottky as this will further reduce packaging size and cost.

Switching ac Supply Pre-Regulator

The ac-supply pre-regulator is a standalone function which can be in principle be connected to any type of SMPS.

As the Ultra High Voltage Supply is only requested today for E-meters and white Goods auxiliary SMPS, the pre-regulator has been designed to provide up to 15W on ~200 Vdc for EU & Asia mains supply from 140 V rms up to 460 V rms corresponding to mains supply between 2 phases.

Despite we could have define with 380 / 400 Vdc clamped output voltage, we did work on a 200 V version to enjoy regulated supply without any variation over mains supply with smaller and cheaper 250 V bulk capacitors type. To increase output voltage, the Vref should be increased using ZD3 and ZD4. The output capacitor C3 and corresponding TVS ZD2 voltages should be changed accordingly.

Circuit Schematic

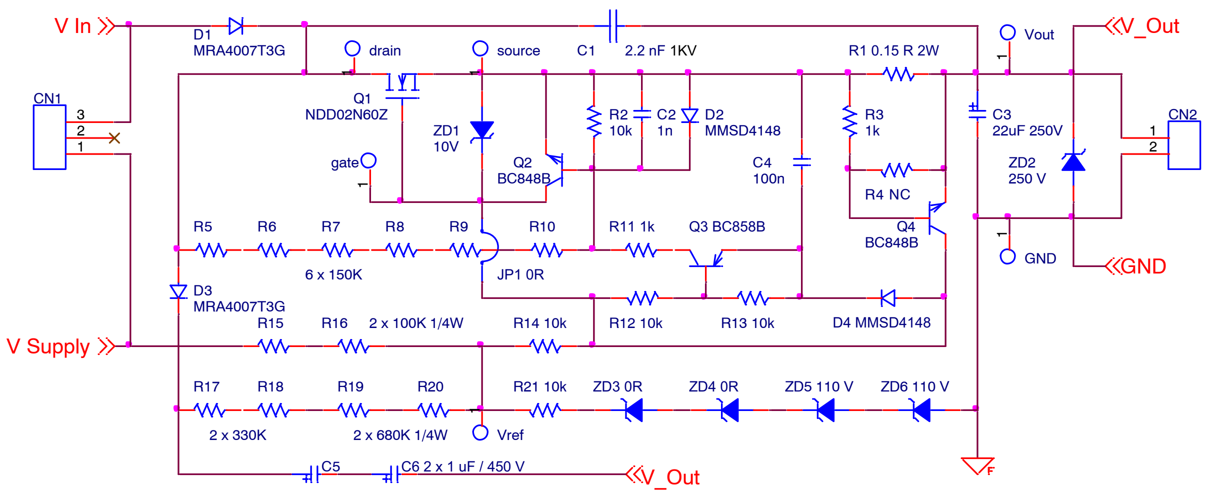

Figure 9. Pre-Regulator Schematic (Patented Application)

Interconnection with SMPS

- Vin: mains input supply after the EMI filter connected to single diode of half wave rectification
- Vout: regulated 200 Vdc supply to be connected to SMPS's bulk capacitor
- VSupply: SMPS's snubber voltage used to supply the regulation circuit and the N-MOS with voltage higher than Vout to allow full saturation of N-MOS during the conduction
- GND inter connection

Circuit description for ON mode

- Thanks to the VSupply from SMPS's snubber, Vref clamped by the Zener ZD3 – ZD6 provides a voltage source capable to drive the Power N-MOS Q1 as soon as the Drain voltage (Vin) is higher than Source (Vout).
- The drain current will follow the slow rising up of mains (Vin) voltage with triangular waveform to charge the output bulk capacitor to the supply voltage.
- The Power MOS is full saturated until Vout is going up to the regulation point.
- As soon as the voltage between Gate (~Vref) and Source (Vout) is down to low level (< 5 V), the Power MOS start to de-saturate.
- When Q1 is no more saturated, the Drain to Source voltage is rising up quickly, following mains voltage shape.
- When Drain to Source voltage of Q1 is up to ~50 V, thanks to resistance divider R5 – R10 and R2, the transistor Q2 is switched ON to drop down the Gate of Power MOS Q1 and speed-up the switch OFF reducing switching losses.
- When Q1 is switching OFF, the Drain voltage is further rising up to secure the drive of Q2 and lock the overall switching OFF process.
- During Q1 conduction time, the capacitor C4 is charged to ~10 V through the diode D4.
- When Q2 is ON, thanks to R11, the transistor Q3 is switched ON to secure the conduction of Q2 until C4 is discharged through R11. This will avoid any conduction of Q1 despite possible strong oscillations on the Drain which may stop Q2. The capacitor C4 should not be too large to be completely discharged after some ms allowing next cycle of conduction (difference between half and full wave rectification).
- If for any reason, the current in Q1 is going over the given limit defined by the resistance R1, the transistor Q4 is conducting, dropping the drive (Gate voltage) of the Power MOS Q1. Q1 will de-saturate and the switching OFF process (using Q2 and Q3) is immediately initiated.

Circuit description for Starting phase

- The starting phase asks for additional circuit as the snubber is not able to provide any supply voltage (SMPS is OFF).
- The only available energy is from the mains supply through Vin.
- Capacitors C5 and C6 are charged to Vin peak voltage through D3 to drive Q1 through resistances R17 – R20.

- Both capacitors C5 and C6 are in series to support any single short circuit (safety tests) without damage. They are connected to Vout instead of GND to reduce voltage applied on the capacitors.
- The Drain / Source voltage control should not be over sensitive else the pre-regulator may never start: if Drain to Source is always keeping Q2 ON before starting, the overall circuit will never start. The capacitor C1 may have some impact as well as a too large capacitor will keep higher voltage between Drain and Source avoiding the voltage to decrease to reset Q2.
- During the starting phase, the cycle by cycle current limitation will be activated, avoiding the current to go over the limit and acting as a perfect Inrush current limiter. This allows removing any Resistance or NTC used as Inrush limiter in SMPS.

Circuit description for Safety tests

- The most critical and common safety tests are the short circuit of electrolytic bulk capacitors.
    - For classical SMPS, these will immediately blow-up the fuse to definitively disconnect the SMPS from the mains supply asking for service and reparation.
    - With the pre-regulator, thanks to the very good current limitation, the power MOS will keep running with the limited current without any thermal run-away. When short circuit is removed, the overall system will go back into normal operation.
- The second critical short circuit is the direct short from Drain to Source of the Power MOS Q1.
    - The current limitation will not be able to limit the current.
    - The voltage on bulk capacitor C3 will be limited by the Transient Voltage Suppressor ZD2 until the mains fuse will blow-up.

Circuit description for EMI and Surges protection

- To reduce EMI, a capacitor is connected between Drain and Source of Power MOS. This capacitor C1 will limit the rising up of Drain voltage and reduce peak voltage and possible high frequency parasitic oscillations on Power MOS coming from overall serial inductances (including EMI filter).
- Thanks to the low switching frequency, we can use a large 2.2 nF without impacting the overall behavior: the capacitor is fully discharged before the next cycle and does not impact the switch-ON behavior.
- This capacitor C1 will also protect the overall pre-regulator again surge tests, limiting the voltage on Power MOS to keep it below MOS's Max rating.
- **Important**: The overall tests on mains connected Power Supplies should be done with special equipments (isolated transformer or ac-source) to provide mains isolation and allow connection of the tests equipments on the board.

The overall following waveforms will show high peak voltages on the Q1 MOS Drain Q1, close to the limit of our 600 V MOS.

- This is linked to tests configuration and use of isolated transformer with huge embedded leakage inductance.
- The fast switch OFF of our Power MOS (compare to classical bridge diodes) generates high negative di/dt which results of voltage spike only limited by the capacitor C1.
- The solution has also been tested with ac-source but the current limitation embedded in that type of equipment will directly affect the current waveform and pre-regulator behaviors.
- Other tests have been done with pre-regulator directly connected on the mains without any isolation while tests have been done with portable oscilloscope working on battery providing full mains isolation. Under that condition, the peak voltage on Q1 Power MOS is very low (below max sinus mains voltage), generated only by EMI filters' inductance when supporting high di/dt.

Pre-regulator behaviors and scope captures

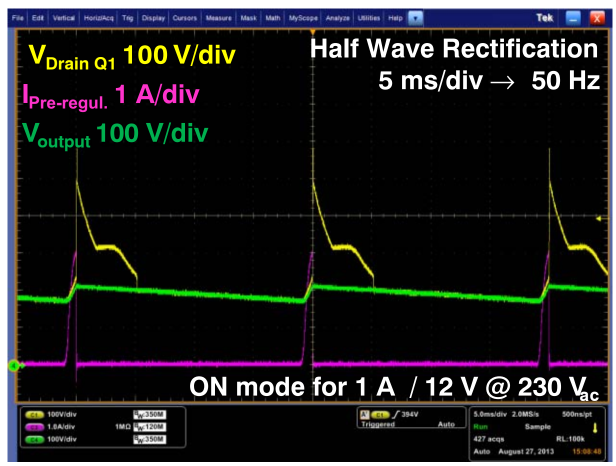

Figure 10. Pre-Regulator Behavior

The high voltage spike on Power MOS is linked to leakage inductance of the isolation transformer been used to allow the tests with standard oscilloscope.

Due to the parasitic diode of Power MOS, the Drain voltage is never much smaller than output.

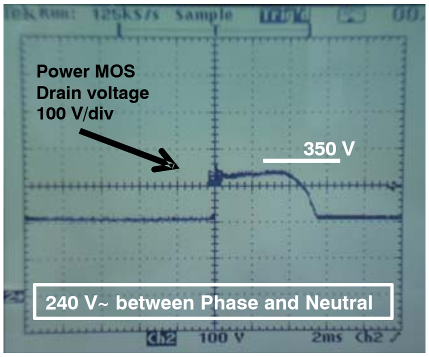

Figure 11. Input and Drain Voltage without Isolation Transformer, Directly Connected on Mains Supply by 240 V Supply between Phase and Neutral

Reduced peak voltage on power MOS (< 350 V) while not affected by large leakage inductance of isolation transformer.

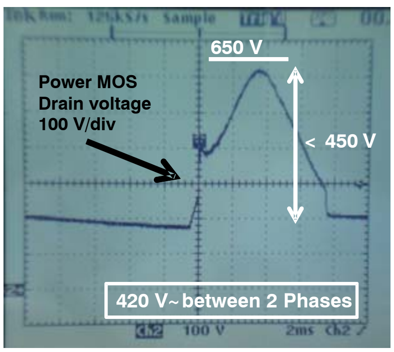

Figure 12. Input and Drain Voltage without Isolation Transformer, Directly Connected on 420 V Mains Supply between 2 Phases

Due to the supply between 2 phases, the voltage is going up to ~620 V but thanks to output voltage > 180 V, the voltage between Drain and Source of our Power MOS stays below 450 V. We may use the avalanche protection of our MOS during the starting phase without issues as this will allows charging the bulk capacitor and avoiding keeping too long this condition.

The issue will be more critical with bulk capacitor shorted to GND and we may consider a higher breakdown voltage MOS (up to 800 V) to sustain both failures (Bulk cap shorted to GND and supply between 2 phases) at the same time. If not, we may break the Power MOS, followed by the fuse as output voltage will be clamped by the output TVS.

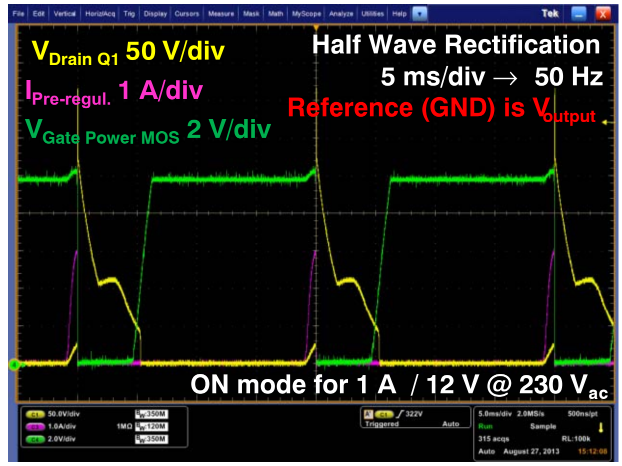

Figure 13. Pre-Regulator Drive & Control

To better understand the driver circuit, GND of the oscilloscope has been connected to output voltage. This allows high vertical resolution of the Gate Source voltage of Q1: The Power MOS is “ready” to drive as soon as Drain to Source voltage is below ~50 V. While mains supply is too low, there is no current flowing through the transistor until mains voltage is above output voltage.

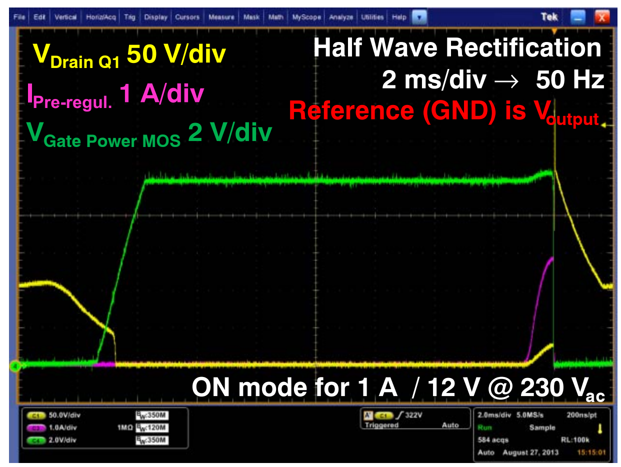

Figure 14. 1 Cycle of Drive & Control

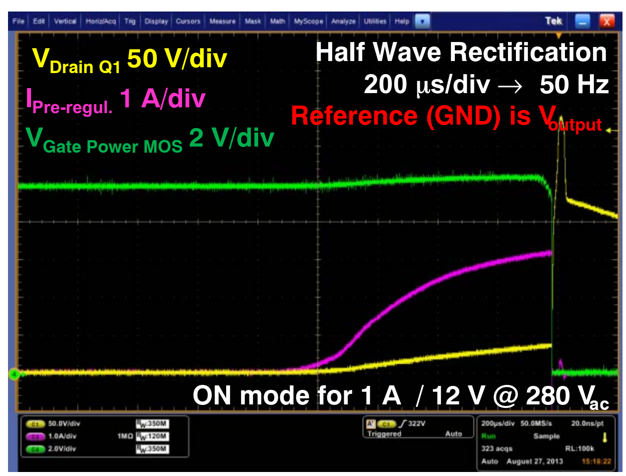

Figure 15. Switching OFF Detail

The current in the Power transistor has a triangular shape rising up until output voltage is at the right level. Then, the regulation circuit will drive down the Gate to switch OFF the Power MOS Q1. The Drain to Source voltage is directly proportional to both Drain current and MOS $R_{DS\text{-}ON}$.

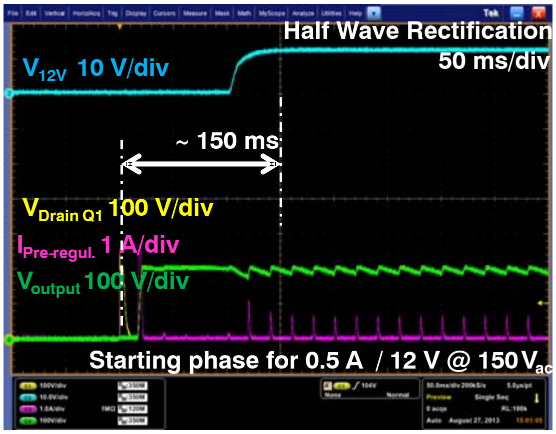

Figure 16. Overall Starting Phase by Low Mains Supply

We do have a very short start-up time: less than 2 mains cycle to get the bulk voltage despite pre-regulator function and < 100 ms start-up type for NCP1075 thanks to his embedded High Voltage Startup.

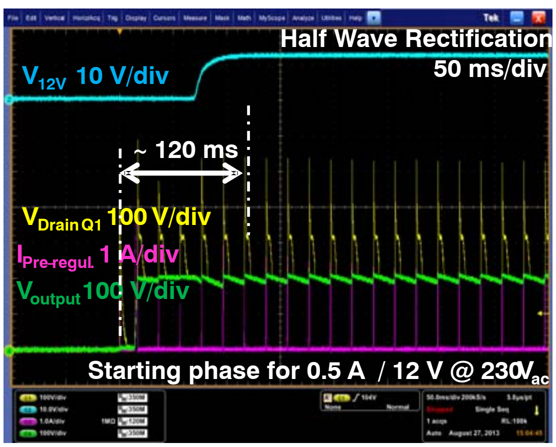

Figure 17. Overall Starting Phase by Nominal Mains Supply

Shorted output bulk capacitor to GND

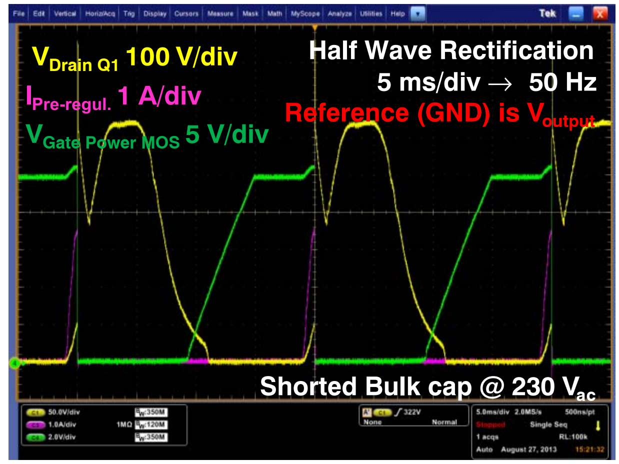

Figure 18. Pre-Regulator Behavior with Bulk Capacitor Shorted to GND

We do have similar behaviors in case of output bulk capacitor short-circuit, with cycle by cycle current limitation without any timer switch OFF.

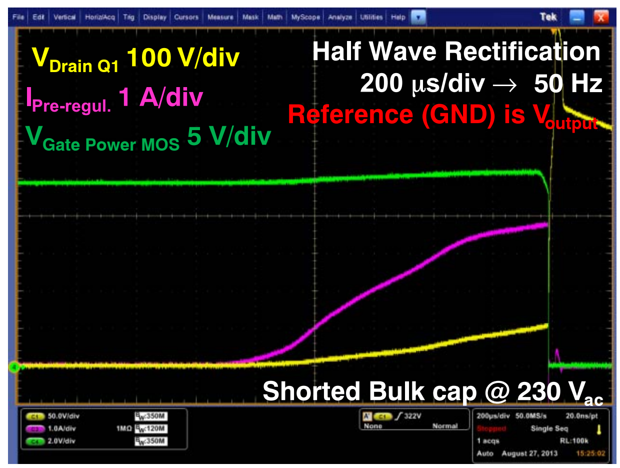

Figure 19. Conduction Time with Bulk Capacitor Shorted to GND

As the pre-regulator is going up to its maximum value, we do have a higher current with corresponding higher Drain to Source voltage (linked to $R_{DS\text{-}ON}$). The higher power dissipation will increase the temperature of the power MOS Q1. Its temperature still stays within acceptable limits.

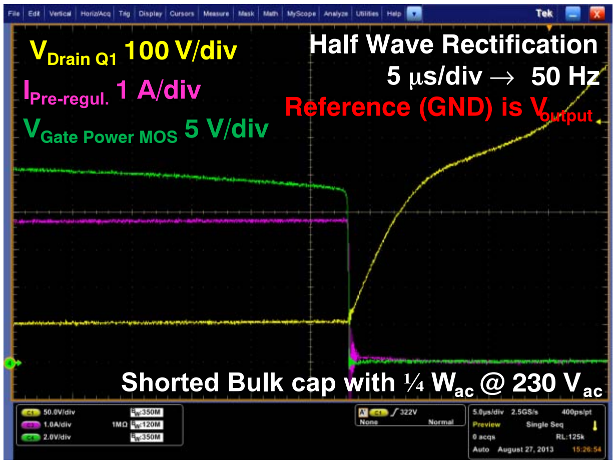

Figure 20. Switching OFF with Bulk Capacitor Shorted to GND

Hold-up time design and Pre-regulator advantages

Hold-up time asks for energy to be stored in capacitors to avoid output voltages to drop down too fast despite mains supply disappears. As most of output voltages are very low (< 12 V), the 1/2 CV^2 (energy stored in capacitor C under voltage V) is much higher with input bulk capacitor.

The hold-up time should be defined for given output power, minimum time to be supported and minimum mains supply voltage to be considered. As the pre-regulator solution will store energy under the same voltage whatever the mains supply is, this solution will provide the same performances over the whole mains supply range (most of applications ask for holdup performances even during low mains supply).

We can see on below scope captures that hold-up time requirements could lead to large input bulk capacitors. This is particularly true for E-meter applications that commonly ask for more than 300 ms, with 2 W output and180 V rms supply.

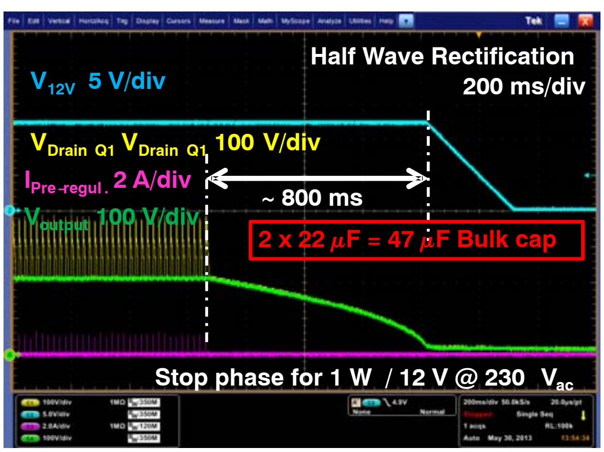

Figure 21. Holdup Time with 47 μF Bulk Capacitor at 1 W Output

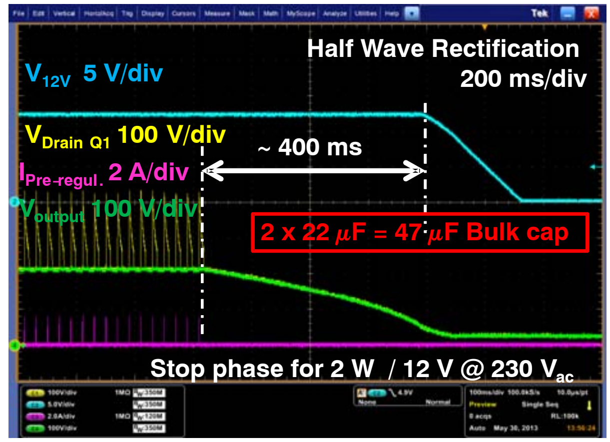

Figure 22. Holdup Time with 47 μF Bulk Capacitor at 2 W Output

To be in line with this specification, SMPS using a pre-regulator section will only need a 47 μF 250 V (12.5 x 20 mm) Bulk cap while a classical solution will require two 100 μF 400 V (16 x 25 mm) type in series to support the high supply voltage (> 600 V). Looking at the size difference, we should expect the 400 V type to be almost 4 times the cost of the single 250 V. If that makes 1/2 US$ price difference for standard 2,000 hours @ 105°C, the difference will be much higher as soon as we move to better technology like 5,000 hours @ 105°C or if the capacitor value has to be increased to sustain more stringent hold up time performances.

As of today, E-meters applications are requesting both, better hold-up time performances with larger bulk capacitors and very long expected life time asking for extremely good electrolytic capacitors. Thanks to the pre-regulator solution, the overall solution can bring both size and cost reduction compared to classical approaches when forced to support Ultra High Voltage Supply (with twice larger 400 V type).

Overall solution advantages

Performances

Thanks to the additional pre-regulator, the Flyback converter performances are improved:

- Improved efficiency with reduced switching losses thanks to smaller and regulated supply allowing smaller snubber and corresponding power dissipation
- Improved regulation performances with smaller t-on and switching frequency Reduced switching frequency range that is critical for E-meter communication quality.

Thanks to the Zero Voltage Switching behavior of the Pre-regulator, his efficiency is very good ~95% according to mains voltage and output power

The overall Pre-regulator and Flyback efficiency is ~75% for nominal mains input range from 5 W to 10 W output.

Table 2. "NO LOAD" CONSUMPTION AND OVERALL (PRE-REGULATOR + FLYBACK) EFFICIENCY

Pre + Fly	"No Load"	1 W	2 W	5 W	10 W
290 Vac	97 mW	66%	71.3%	74.6%	71.4%
264 Vac	82 mW	66%	71.8%	75.3%	73.5%
230 Vac	67 mW	67%	72.4%	76.2%	74%
180 Vac	55 mW	68%	72%	79%	77%
150 Vac	43 mW	74%	77.5%	77%	81%
90 Vac	29 mW	77%	79%	75%	74.4%

Size

Compared to the cascode solution, the size of the added Power MOS is similar with ~2 cm^2 of SMD parts to be added for the more complex control parts. On the other side, we don't use Inrush limiter and sizes of overall large bulk capacitor are much reduced.

The overall size of Power converter is much smaller when built with pre-regulator allowing height to be easily < 25 mm with 250 V bulk capacitor (much more difficult with larger 400 V type).

Cost

Compared again to cascode solution, the cost of the added Power MOS and the overall control parts (including TVS and Inrush limiter) is similar for both solutions (larger number but lower cost for Pre-regulator parts).

The cost difference is mainly related to Bulk capacitor. As explained before, while 400 V type should be twice of double value, we easily come-up with 1/2 US$ to 1 US$ cost difference according to capacitor values and technology. Compare to the overall Power converter cost, this corresponds to ~30% cost saving when built with ON Semiconductor Pre-regulator solution.

Possible Evolution of Pre-Regulator Solution

Full wave rectification

Despite the solution is capable to work with full wave rectification, due the higher frequency, we may get issue if the voltage on Power MOS stays above the switch ON level.

Due to C1 and C4 time constant, we may keep the system locked and not allow switching ON again. This will be even worse if C1 is increased to improve surge immunity.

3 Phases supply

Due to the 3 phase interleave, the input / Drain voltage of Power MOS will not go down so much, not allowing Q2 to be switched OFF to allow next cycle for Q1. The resistance divider controlling the des-saturation of Q1 should be change to be less sensitive. This is particularly critical for the start when output voltage is zero (Please refer to table 1 for overall possibilities).

400 V Clamped

Instead of Pre-regulator, the solution can be used as simple voltage clamp, providing mains voltage supply until 264 V rms while clamping when exceeding for abnormal function. This is simply done by increasing the voltage reference Vref with added Zener diode on position ZD03 and ZD04.

If this makes the pre-regulator "transparent" for normal supply condition with full saturated Power MOS and single 450 V Bulk capacitor, this does not allow the post Flyback converter to be changed compare to original design (no reduced snubber, same diodes and voltage margin).

With this solution, we can detect when the clamp is activated (current going through ZD03 to ZD06) to provide a control line and act accordingly. We may switch OFF the Flyback converter or provide default information to control part.

Reduced output voltage down to 120 Vdc for US applications

Despite there are less advantages for US market with reduced mains supply, this pre-regulator could also be designed with 120 V output, build with single 160 V Bulk capacitor. Considering that US could support any failures conditions with classical Wide Range SMPS and single 400 V Bulk cap, we don't see much advantage with the Pre-regulator solution.

Surges Tests

For classical Power Supply, the large bulk capacitor in front of any semiconductor device helps to protect the overall system again peak voltage excursions / surges on mains supply.

For our new solution, this is valid for the post Flyback converter but not any more for the pre-regulator function directly connected to the mains (after the rectifier diodes).

The original NCP1075 was not designed to be connected to the added pre-regulator. To improve Surge Tests behaviors, the Power Supply designers should implement below recommendations:

- Increase the X2 Capacitors up to 2 x 200 nF and place them on each side of a 10 mH common mode EMI filter instead of single coils used in NCP1075 evaluation board
- Add a 250V MOV directly connected on mains input

With above modifications implemented, the overall solution pass 2 KV differential mode and 4 kV common mode surge tests.

However, if such tests are performed in a real E-metering application with its embedded protections, the pre-regulator should not ask for any added filtering to allow the solution to pass the most severe surge tests.

Conclusion

The ON Semiconductor Pre-regulator solution has been developed to support extremely high input voltage supply. If the solution is not capable to support 3 phase supply, it is perfectly design for single phase supply wrongly connected between 2 phases as requested for most of E-metering applications.

The pre-regulator solution allows design

- Using 1 single 250 V bulk cap instead of 2 units twice bigger value 400 V type
- Using single 700 V integrated switcher instead of 1000 V or more Power MOS + discrete controller or cascode configuration
- Using simple transformer and smaller secondary diodes thanks to the regulated Vin coming out of the pre-regulator

Thanks to single lower voltage bulk capacitor, the overall system can still comply with large holdup time. The single capacitor provides space and cost saving compared to classical approaches that require 2 big capacitors and balancing resistances.

The reduced 250 V type bulk capacitor allows design to use better technology capacitors providing extended life time for high ambient temperatures (5000 hours @ 105°C with CFX from Rubycon) with a very limited cost up when compared to 400 V type. This is a key point for system requested to have over 10 years life time under severe conditions.

BILL OF MATERIAL

Table 3. BOM OF 15 W / 200 V PRE-REGULATOR

Position	Component Type	Value	Rating	Pkg / Dimensions	Reference	Supplier
C1	Ceramic Cap	2.2 nF	1 kV	Radial 5 mm	CK45-B3AD222KY VNA	TDK
C2	Ceramic Chip Cap	1 nF	10 V	0805		
C4	Ceramic Chip Cap	100 nF	10 V	0805		
C3	Electrolytic 105°C	22 μF	250 V	Radial 5 mm D10 x 16 mm	PX 105°C	Rubycon
C5	Electrolytic 105°C	1 μF	450 V	Radial 5 mm D6.3 x 11 mm	PX 105°C	Rubycon
C6	Electrolytic 105°C	1 μF	450 V	Radial 5 mm D6.3 x 11 mm	PX 105°C	Rubycon
D2	Diode Fast	MMSD4148	100 V, 0.2 A	SOD-123	MMSD4148	ON Semiconductor
D1	Diode	MRA4007T3G	1000 V, 1 A	SMA	MRA4007T3G	ON Semiconductor
D4	Diode	MMSD4148	100 V, 0.2 A	SOD-123	MMSD4148	ON Semiconductor
D3	Diode	MRA4007T3G	1000 V, 1 A	SMA	MRA4007T3G	ON Semiconductor
JP1	Carbon Chip Resistor	0R0		1206	0x00	
Q1	Power MOS	NDD02N60Z	600 V, 2 A	DPAK	NDD02N60Z	ON Semiconductor
Q2	NPN Transistor	BC848BLT1G		SOT-23	BC848BLT1G	ON Semiconductor
Q3	PNP Transistor	BC858BLT1G		SOT-23	BC858BLT1G	ON Semiconductor
Q4	NPN Transistor	BC848BLT1G		SOT-23	BC848BLT1G	ON Semiconductor
R1	Wirewound Resistor	0.15, 5%, 2 W		TOP Manual Axial 22.5 mm		
R2	Carbon Chip Resistor	10K		0805		
R3	Carbon Film Resistor	1K		0805		
R4	Carbon Film Resistor	NU		0805		
R5	Carbon Chip Resistor	150K		0805		
R6	Carbon Chip Resistor	150K		0805		
R7	Carbon Chip Resistor	150K		0805		
R8	Carbon Chip Resistor	150K		0805		
R9	Carbon Chip Resistor	150K		0805		
R10	Carbon Chip Resistor	150K		0805		
R11	Carbon Chip Resistor	1K		0805		
R12	Carbon Chip Resistor	10K		0805		
R13	Carbon Chip Resistor	10K		0805		
R14	Carbon Chip Resistor	10K		0805		
R15	Carbon Film Resistor	100K	1/4 W	Axial 12.5 mm		
R16	Carbon Film Resistor	100K	1/4 W	Axial 12.5 mm		
R17	Carbon Chip Resistor	330K		0805		
R18	Carbon Chip Resistor	330K		0805		
R19	Carbon Film Resistor	680K	1/4 W	Axial 12.5 mm		

1. Resistor tolerances are ±5% unless noted otherwise
2. Capacitor tolerances are ±10% unless noted otherwise
3. Electrolytic capacitor tolerances are ±20% unless noted otherwise

Table 3. BOM OF 15 W / 200 V PRE-REGULATOR

Position	Component Type	Value	Rating	Pkg / Dimensions	Reference	Supplier
R20	Carbon Film Resistor	680K	1/4 W	Axial 12.5 mm		
R21	Carbon Chip Resistor	10K		0805		
ZD1	Diode, Zener	MMSZ5240BT1G	10 V	SOD-123	MMSZ5240BT1G	ON Semiconductor
ZD2	Diode, Transil	P6KE250A	250 V	Axial 12.5 mm	P6KE250A	STMICRO
ZD3	Carbon Chip Resistor	0R		0805		
ZD4	Carbon Chip Resistor	0R		0805		
ZD5	Diode, Zener	MMSZ5272BT3G	110 V	SOD-123	MMSZ5272BT3G	ON Semiconductor
ZD6	Diode, Zener	MMSZ5272BT3G	110 V	SOD-123	MMSZ5272BT3G	ON Semiconductor
CN1	3 poles connectors				282836-3	TE Connectivity
CN2	2 poles connectors				282836-2	TE Connectivity
Drain	Single Pin				TSW-101-07-T-S	SAMTEC
Source	Single Pin				TSW-101-07-T-S	SAMTEC
Gate	Single Pin				TSW-101-07-T-S	SAMTEC
Vref	Single Pin				TSW-101-07-T-S	SAMTEC
Vout	Single Pin				TSW-101-07-T-S	SAMTEC
GND	Single Pin				TSW-101-07-T-S	SAMTEC

1. Resistor tolerances are ±5% unless noted otherwise
2. Capacitor tolerances are ±10% unless noted otherwise
3. Electrolytic capacitor tolerances are ±20% unless noted otherwise

Overall (Pre-Regulator & NCP1075 Flyback) Board Picture

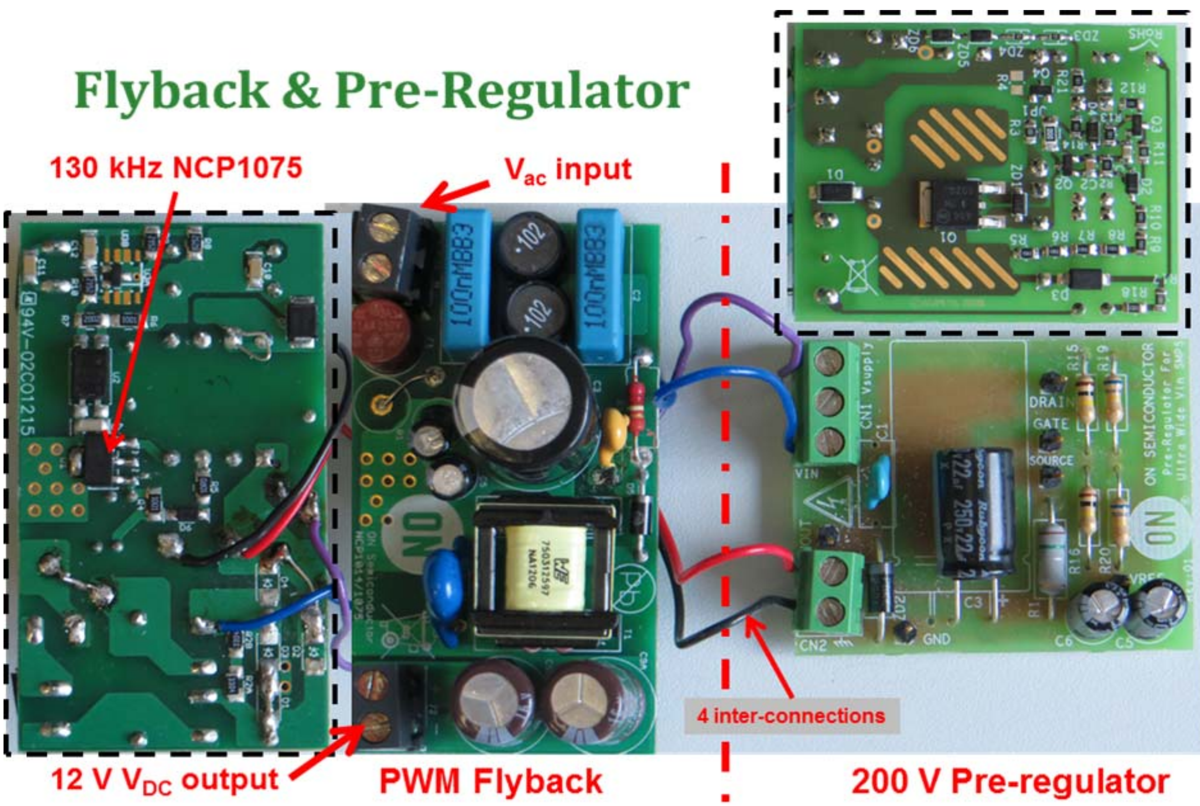

Figure 23. Overall (Pre-Regulator & NCP1075 Flyback) Board Picture

Pre-Regulator Board (50 mm x 40 mm)

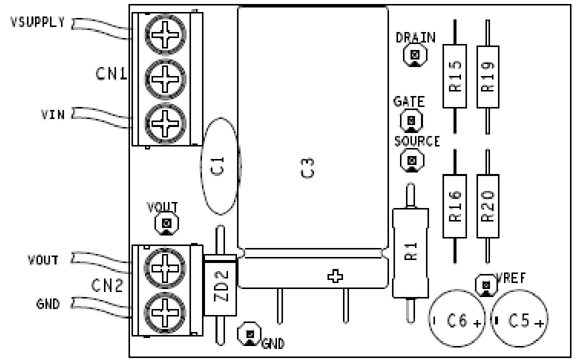

Figure 24. Pre-Regulator Board - Top Side

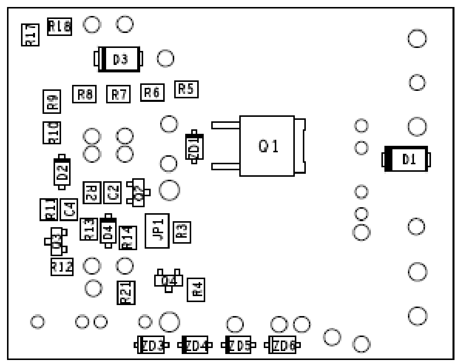

Figure 25. Pre-Regulator Board - Bottom Side

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303-675-2175 or 800-344-3860 Toll Free USA/Canada
Fax: 303-675-2176 or 800-344-3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800-282-9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81-3-5817-1050

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative