Turn-ON characterization of Front-End Rectifiers

Abstract

A critical step in rectifier design is the fine tuning of a set parameters to achieve the desired functionality of the final product. Turn-ON performance is one such fine tuned parameter that controls the magnitude and duration of permissible current surges during startup while concurrently shielding the power train from potentially damaging overloads. The ultimate goal is to ensure that the front-end rectifier power system properly starts into the end-system it powers under all conditions.

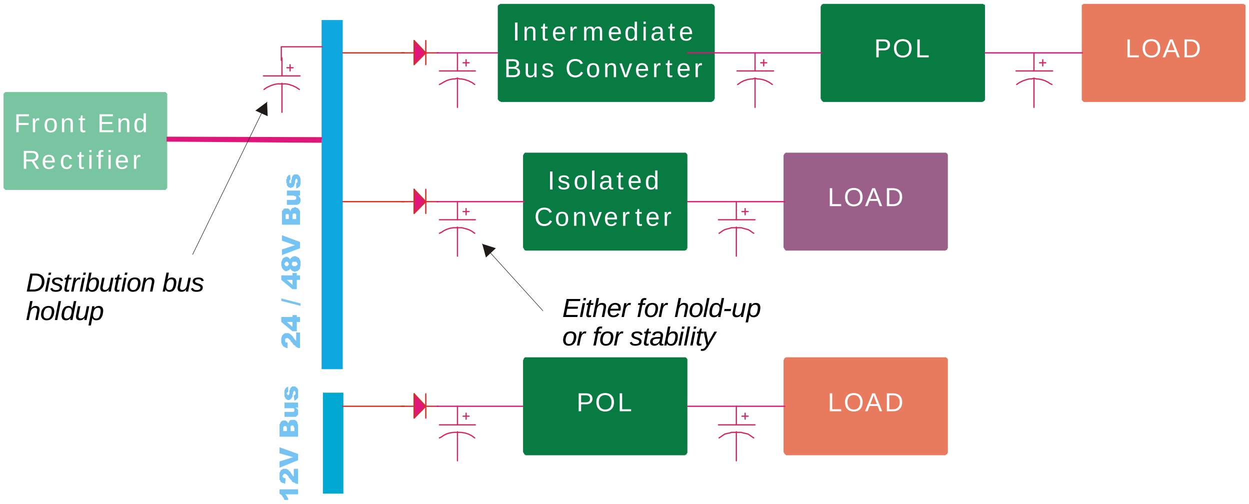
Verification of the turn-ON performance of the rectifier is often performed using electronic loads that simulate the end-use environment of the power system. The latest market trend for some of these electronic loads is to offer a constant-power mode capability. This trend is desirable because in distributed power systems constant-power emulates more precisely the power drawn by post dc-dc converters. In this paper we summarize our testing of two such constant-power loads, one manufactured by Chroma and the other by TDI. The test data shows that these electronic loads when set to the constant-power mode may inhibit rectifier start-up under certain conditions. It is prudent to understand the prevailing control dynamics during start-up and recognize that the constant power setting of the electronic loads may indeed prevent start-up because of their inherent control mechanism.

We should annotate that we observed start-up difficulties under certain set-up conditions only when the electronic loads were programmed and connected prior to start-up of the power system. If the electronic loads engaged after the power system was already up then we did not observe any peculiarities. Some of the start-up dynamics between the power system and the electronics loads are unavoidable. Understanding the cause for these abnormalities rationalizes the reason for these start-up issues and assists in quantifying whether the power system performs properly.

In this paper we first characterize the desired simulated performance characteristic. We follow this theory with recording the start-up dynamics when a power system turns-ON into a bank of dc-dc post converters. These results are then compared to the results of turning-ON into a constant resistance mode setting of the electronic loads. This comparison is important because many developers are still utilizing the constant resistance mode setting of the electronic loads and with good reasons, it works at simulating the post converter performance and achieves quick and accurate results. Lastly we record and explain the start-up characteristic when the electronic loads are set to the constant power mode.

System Characterization

In typical distributed systems power is being fed into a bank of capacitors followed by the post dc-dc converters. These capacitors either hold up the bus during fuse clearing transients or provide input filtering for stability considerations of the post dc-dc converters. Following these capacitors are the dc-dc converters that convert the bus voltage to voltage levels required by the board electronics. The front-end rectifier must be able to charge these capacitors and then provide the energy demands of the post dc-dc converters.



A typical distributed power system

The turn-ON current surge of the post conversion stage is fairly benign because the turn-ON sequence commences only after the bus voltage reaches a pre-determined threshold, followed by soft start that ensures a steady rise of demanded power rather than a sudden application of instantaneous power. Later in the paper we show the turn-ON behavior of Lineage Power's CP front-ends powering a bank of Isolated Converters with a set of capacitors in front of each converter.

Although the output voltage of front-ends varies between 12Vdc and 48Vdc, the focus of this paper is on the behavior and testing of 48V front-ends. However, the testing methology and conclusions drawn from these tests are equally applicable to all families of front ends independent of their output voltage level.

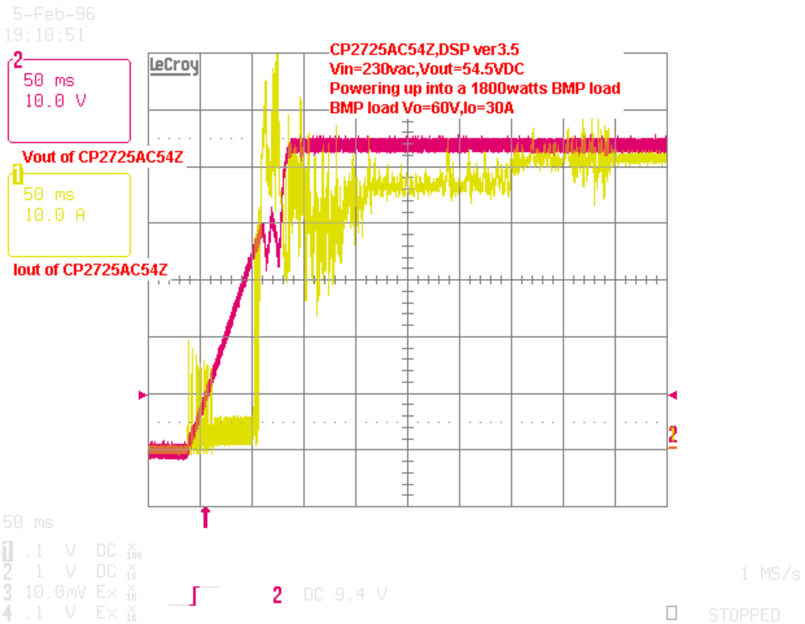
Converter turn-ON characterization

The largest market segment of converters operates over an input range from 36Vdc to 75Vdc covering the voltage swings of both 48V and 60V battery plants of telecom systems. The turn-ON voltage of these converters is around 34Vdc. When the voltage exceeds the input voltage turn-on threshold, the converter initiates a soft-start.

Another set of converters targeting the wireless telecom market operates over an input range of 18Vdc to 60Vdc covering the needs of 24V or 48V battery plants. Plant voltage selection is predominantly being driven in these systems by the power requirements of the power amplifiers since they comprise over 2/3 of the load. The turn-ON voltage of these converters is around 16Vdc. Although the contents of this report do not focus on these latter wireless converters, the conclusions are equally applicable to them.

Turn-ON performance using a load bank of dc-dc converters

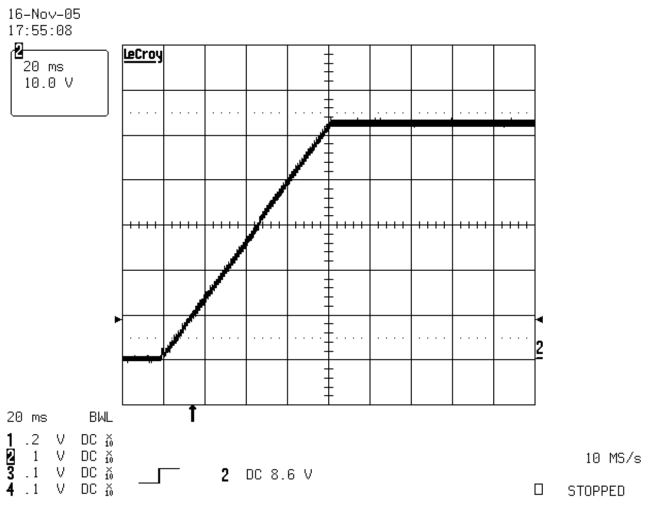
In the graph below we captured the turn-ON behavior of a single CP2725AC54 rectifier powering a bank of dc-dc converters loaded to 1800 watts of output power. This is reasonable for a 2725 watt rectifier to see during turn-ON because systems are at a much lower power level during turn-ON than during normal operation. Processors are at idle, traffic is at zero, and memory would not be active during turn-ON. Thus, systems demand much lower power levels at turn-ON than at full power capacity when they must provide power during peak traffic, full processing speeds and peak operating modes. In the waveform channel-2 in red is Vout – 10V/div, and channel-1 in yellow is Iout – 10A/div. period – 50ms/div



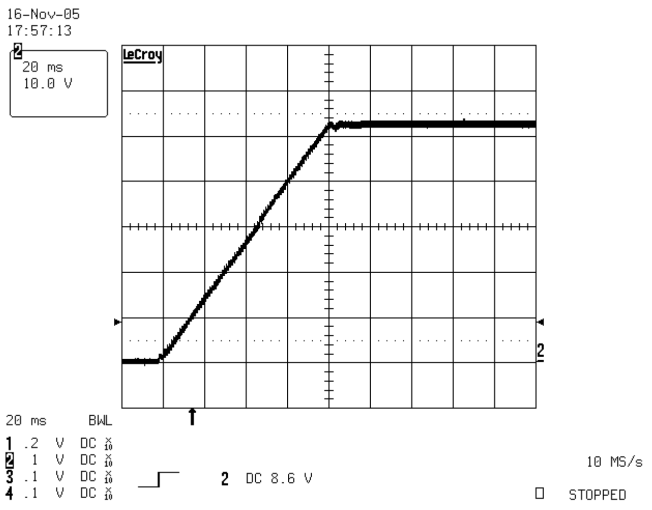
The initial current spikes at the start of the ramp are current surges into the capacitors at the input of the converters. Seldom do rectifiers have difficulty handling this inrush. The converters start their turn-ON at around 40Vdc. The trigger started at around 34Vdc, but the module's turn-on delay postponed the turn-ON transient until the bus voltage rose to 40Vdc. The hefty initial current surge caused a dip in output voltage and is indicative of insufficient bus capacitance to ensure that this dip would not occur. The voltage dip stopped at 33Vdc. This is where the converters turned OFF because of low input voltage. After a second dip, the current surge decayed sufficiently to maintain the converters ON. Our objective was to evaluate turn-ON performance and not to fine tune system behavior to eliminate the voltage dip during the turn-ON process.

Evaluations using the resistive mode of electronic loads

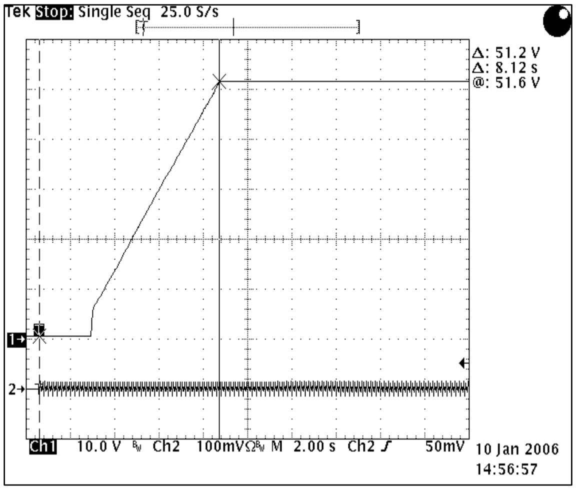
As we stated above, until recently, turn-ON characterization of the power system was verified using the resistive mode setting of electronic loads and this mode yielded well defined and predictable waveforms. In this mode the electronic load does not stress the rectifier beyond its ratings unless specifically set to do so. As can be seen from the recorded waveforms below the resistive setup adequately simulates the startup characteristic that a typical system with post regulators would demand. These waveforms were obtained under various load settings using the Lineage CP1800AC52 and CP2000AC54 rectifiers.



CP2000 - Startup in I^2C mode – 10A load, 7 rectifiers in parallel – Resistive mode, Trace 1 - Vout

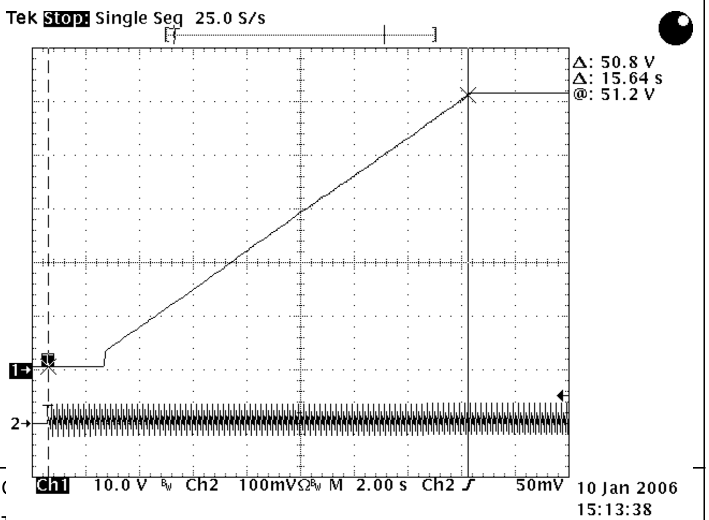


CP2000 - Startup in I^2C mode – 35A load, 2 rectifiers in parallel – Resistive mode, Trace 1 - Vout



CP1800 - Startup RS485 mode – 11.5A load – Resistive mode,

Trace 1 – Vout, trace 2 – Vin



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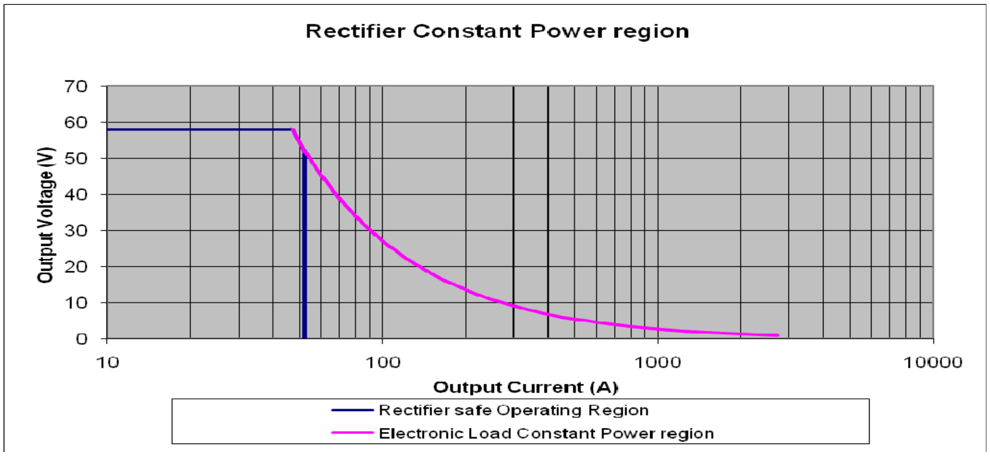
Trace 1 – Vout, trace 2 – Vin

The conclusion from these tests is that the front-end rectifier turn-ON as observed by the voltage rise of the bus is very similar between the voltage rise of the actual load bank and that obtained when the electronic loads were set to resistive mode. (albeit, excluding the dips caused by insufficient bus load capacitance). Therefore, the resistive mode of operation of the electronic loads precisely simulated the actual environment even without resorting to any turn-ON voltage control.

Evaluations using the constant-power mode of electronic loads

The dynamics of start-up are much more difficult to control in the constant-power mode and manufacturers resort to different means to handle this paradox. Imagine a very small system of around 2kW that begins to start up. If the output voltage is only 1Vdc then the electronic load should demand over 2000 amperes to provide the 2kW of power. This is a huge amount of current for either the electronic load to sink or for the power system to source. In practice neither piece of equipment is designed to handle such large transients and so limitations are employed.

Practically, if the electronic load demands a higher current level than the rectifier is programmed to deliver than the rectifier will current limit its output in order to protect its internal circuitry. The following graph shows the current demand of a constant-power mode set electronic load and the fold down current limit of Lineage Power's CP2725 rectifier. The grape colored line plots the current level requested by the electronic load to deliver a constant power of 2725 watts. The vertical blue colored line plots the fold down current limit of the CP2725 rectifier. If the electronic load would demand more than about 53 amperes then the rectifier would go into current limit and lower its output voltage. Its output voltage would be determined by the load resistance that the electronic load would be adjusted to. Needless to say that if the electronic load would attempt to start at 1Vdc, the resultant power level being delivered will be less than the electronic load is asking for. Unless this status-quo is somehow disturbed by the control circuitry the system will not start up.



CP22725AC54 safe operating region vs power demanded by electronic loads

A number of transient states could offset this steady-state stale-mate condition. One is the inadvertent delay of the output current limit circuit of the rectifier that may satisfy the initial surge demand of the load. Another is either a delay in turn ON or a slow soft start of the electronic load that would limit the instantaneous current demand. Whatever it is, something must trigger an alteration of the steady-state condition.

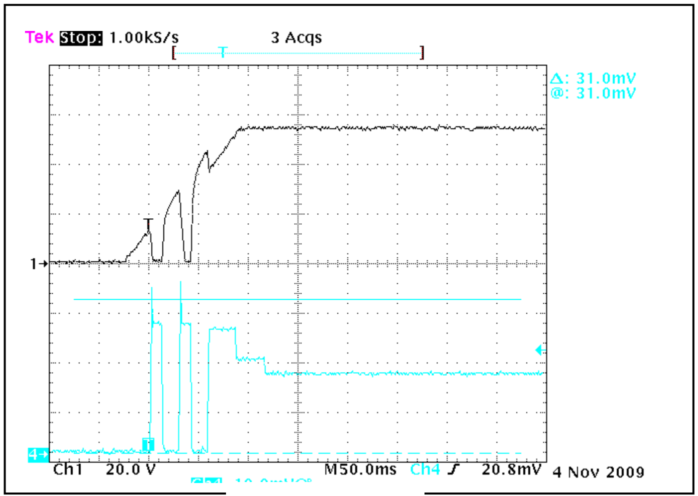
Other helpful triggers are to program the electronic loads so that they would not start up until the bus voltage is above that point where the modules would start up, and simultaneously reduce the initial power being applied to around 20 – 30% of the rectifier capacity. These are all reasonable initial conditions to better simulate what the modules would do. But in the end these are all changes to the steady-state condition that may be sufficient to provide the kick required to start up the system.

In the tests that follow we tried a number of these triggers to see whether they would have an impact to the start up feasibility of the power system-electronic load combination. Of course, they helped significantly and in many cases resulted in an eventual start up of the power system. But the fundamental issue is still there. Without a start-up trigger mechanism the power system will not start up.

Response of the Chroma model 63203A electronic load

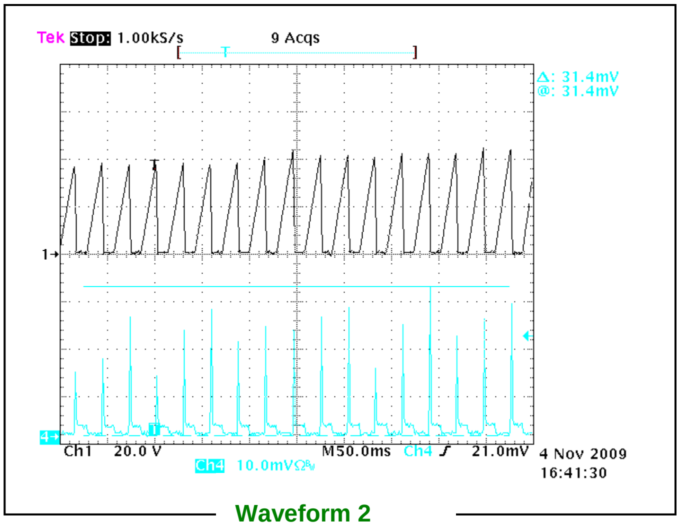
In our second set of tests of the front-end consisted of a shelf of 4 CP2725AC54 rectifiers providing power into a Chroma model 63203A electronic load having a power capacity of 6000 watts or 600 amperes. We observed a number of peculiarities using this load, one being that the start-up behavior was not repetitive for consecutive turn-ON events. The start voltage was factory set at 0Vdc for the first set of tests. Out of 10 attempts maybe 8 different start-up characteristics were captured. In the following two waveforms we set the load to 4kW, about 40% of the capacity of the power system. The output voltage of the rectifier shelf is at 20V/div, the output current captured by a 100A rated current probe is at 50A/div. Period is 50ms/div. In waveform 1 the power system goes into current limit during the start-up on two different occasions. The electronic load sees the collapsing voltage and turns OFF for a pre-set duration. This off-time causes recovery from current limit and permits the power system to continue to climb its soft-start ladder. By the third attempt sufficient voltage exists for the load to limit its current demand below the current limit of the rectifiers.

This is one of the triggers we alluded to in the introduction to power limit turn-ON. The Chroma load executes a turn-OFF followed by a delay and a subsequent turn-ON. The current drain calculation gets recomputed with every turn-ON. Whether a successful turn-ON is yielded depends on when the voltage measurement is taken for a specific power computation and how much current is programmed to be drained to meet the power capacity demand requirement.



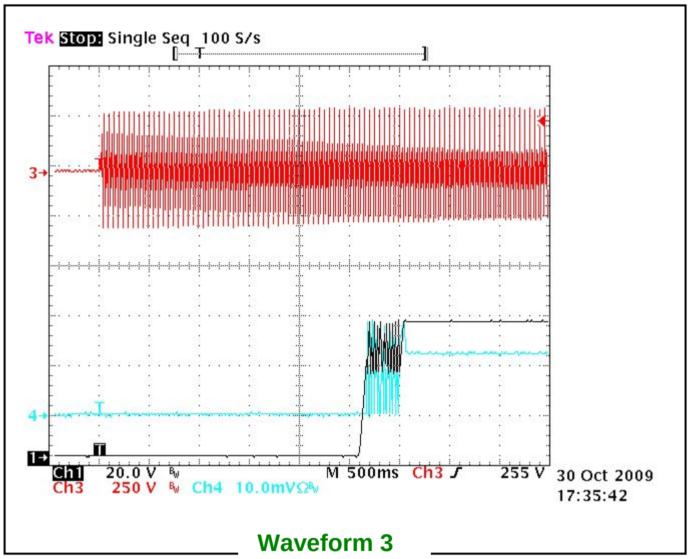
Waveform 1

Waveform 2 shows the response to the same identical setup as before. Here the electronic load demands significantly higher current levels than in the first waveform as can be deduced from the rapid fall time of the output voltage of the power system. We cannot explain the behavior of the load here. The power system voltage is higher than in the first waveform yet the demanded instantaneous current is also significantly higher than before. This rapid ON/OFF cycle continued for 20 seconds after which the power system executed a hiccup; turned OFF, timed out for 9 seconds, and re-started without soft start. Rapid rise instead of soft-start triggered a turn-ON . But it took 30 seconds for an eventual start-up. Vout – 20V/div, Iout – 50A/div, period – 50ms/div. For clarity, this rapid rise event is not shown here.



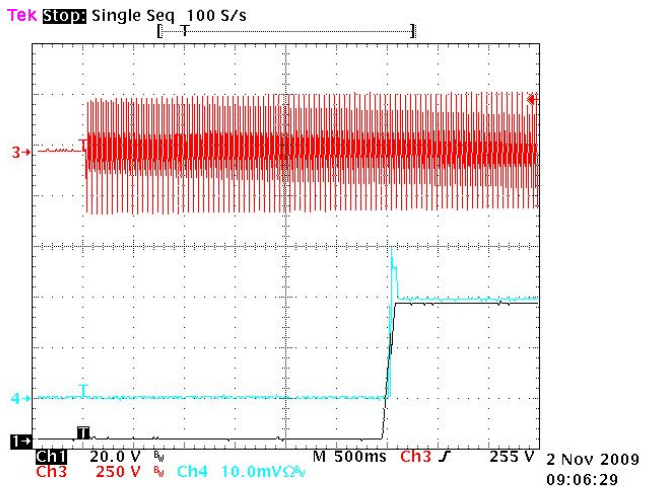
Waveform 2

In our next set of tests the Electronic Load was first warmed up at 4kW for 20 minutes because more consistent results were obtained when the Chroma load warmed up. The Von state was also changed from 0Vdc to 34Vdc. Data was taken at different load settings. Waveform 3 shows one of the setting faults of the Chroma load. The Von setting is also the Voff setting by design. The hysteresis is very low, maybe around 200mV. So if the output voltage momentarily drooped as current is applied the load turned OFF and then attempted a restart. There is no way to adjust the Voff point hysteresis. Settings: 3kW power, 4 units, 20V/div, 50A/div. Upper waveform is the AC input to the power system.



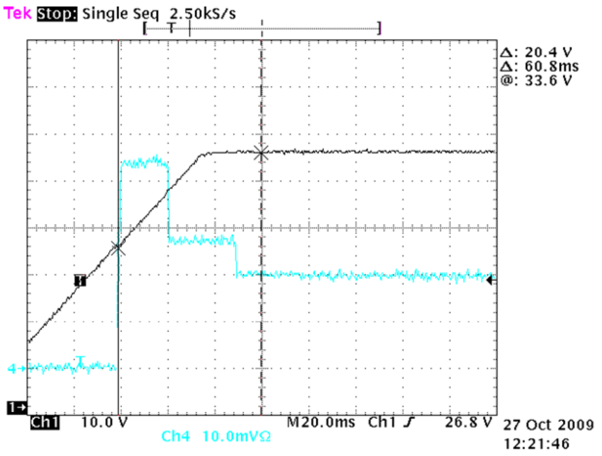
Waveform 3

Waveform 4 setup: 5kW power, 4 units, 20V/div, 50A/div. Upper waveform AC input. This waveform is about as close to an ideal waveform as one can get. A more strenuous set up yet much better response.



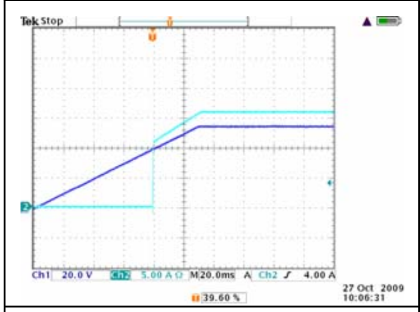
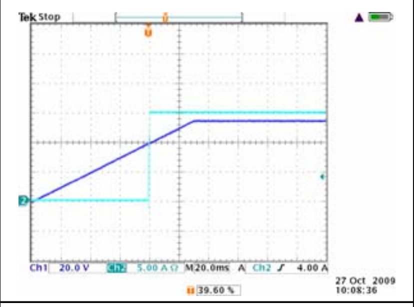
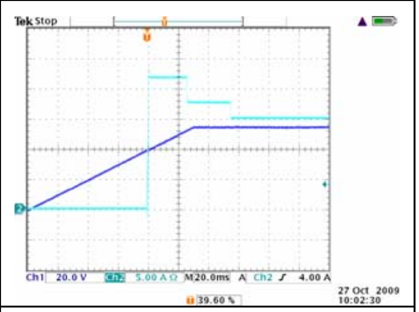
Waveform 4

Waveform 5 setup: 2kW power, 4 units, 20V/div, 50A/div. Upper waveform AC input. This waveform shows a three step current calculation of the Chroma load at around 30ms intervals. The first estimation of power capacity is about 25% higher than the 2kW setting. The load stays in a constant current mode until it has time to recalculate the required current level even though the voltage continues to increase.



Waveform 5

For comparison purposes, the following waveforms show the bus voltage and load current imposed on a single CP2725AC54 rectifier at the various mode settings of the Chroma load with the following parameters; turn-ON voltage 40Vdc, output power 800 watts, minimum slew rate. Output voltage is 20V/div, output current is 5A/div, period is 20ms/div. The CP platform is designed to turn-ON in 100ms. These waveforms confirm that the turn-ON characteristics of the various mode settings are identical and represent theoretical expectations in situations where the front-end power system does not current limit during the start-up process.

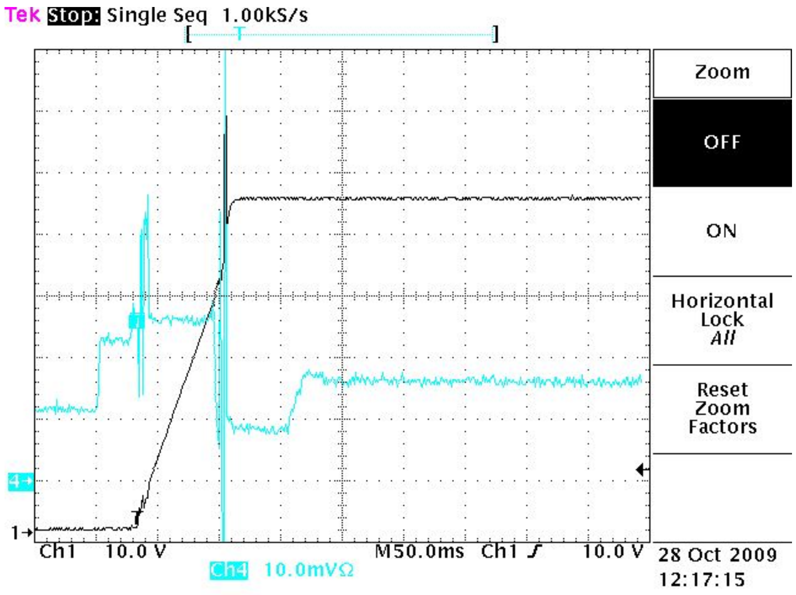
		
Constant resistance mode	Constant current mode	Constant power mode

TDI Dynaload RBL488 electronic load

TDI is another manufacturer that offers an electronic load with constant power capability. Although the manufacturer's manual suggested that that load can be configured to power ON either at Von=0, or at a setting chosen by the programming features, we were not able to program Von control. In discussions with the manufacturer it became clear that our loads required a software update in order to control the Von turn ON state. The behavior with this modified ON control has not yet been verified.

Testing with this TDI load revealed a number of differences when compared to the Chroma load. An important observation was that the turn-ON waveform showed a similar signature with each successive turn-ON into the same set-up. This was an important observation because it substantiated that the dissimilar start-up signatures when the Chroma load was connected is a function of the Chroma load control circuitry and not the power system. A second observation was that during the turn-ON event two instability areas were seen, one at a low output voltage and the other around 52Vdc. The voltage spikes captures on the screen are likely to be inductively coupled at the point of measurement because the rectifiers did not trip for overvoltage.. The system always turned ON even though the waveform above the 90% point is not consistent with previously recorder data either using real modules or the Chroma load. This type of instability was not observed with the Chroma load where every ON/OFF sequence was precisely explained and so we believe that this type of peculiarity captures the behavior of the TDI load and not the power system.

Our testing with the TDI load was rather limited because we were not able to control the turn-ON voltage level and therefore we were not able to simulate turn-ON characteristics of the post dc-dc converters. Waveform 6 shows the response of the TDI electronic load when set to 4kW with 3 CP2725AC54 rectifiers in parallel. Other load combinations showed a similar start-up waveform.



Waveform 6

Conclusion

Testing the turn-ON performance of rectifiers is not trivial when the power system is mated to commercially available electronic loads in the constant-power setting. The Chroma and TDI loads exhibited totally different start-up characteristics. The TDI Dynaload exhibited some form of a controlled soft-start while the Chroma load is more likely to demand significant power instantaneously from the front-end power system.

Performance of the Chroma load improved when a start up voltage was introduced. But even the selection of this feature had its peculiarities. The load tended to turn ON and OFF in rapid cycles even at the slight deviation of the output voltage. An additional feature that would have kept the load ON once it started did not work well and made the response much less predictable. We found the Chroma load much better behaving once the internal electronics in the load were warmed up. In a number of instances the Chroma load did not respond as expected even though readings of its settings did not show any peculiarities. The only form of meaningful recovery from these instances consisted of powering OFF the load, waiting for about a minute and then repowering the load. This step cleared the internal registers of the electronic load. This form of restart worked every time and the load reset into a predictable state. The power system started in every instance, albeit under some conditions it took as long as 30 seconds.

We also demonstrated that placing these electronic loads into their resistive mode more precisely represented the start-up characteristics of a real system with post dc-dc converters.

Our testing concluded that these loads do not behave flawlessly during start-up when programmed into their constant-power mode of operation. It took us some time to capture and understand precisely what is going on during start-up and be able to rationalize what is happening, why, and what can be done to improve the simulated setup in order to get meaningful data. These intricacies are concerns only during start-up of the power system-electronic load combination. If the load is connected after the power system is already powered we did not observe any peculiarities.