AMETEK's MX Series Programmable Power Source Operating In *Regenerative Mode* (SNK Option)

Introduction

The California Instruments MX Series Programmable Power Sources, by AMETEK Programmable Power (AMETEK), can be specified with either Source (Normal) or Regenerative Mode (SNK) options. With the latter, the MX Series can "sink" rather than "source" power, hence the "SNK" designation for this option. In operation, SNK settings determine how the MX performs in the Regenerative Mode when the MX receives power returning from the equipment to which it is connected. This application note describes the typical operational characteristics of the MX in Regenerative Mode, using either the front panel or the MXGUI control software to implement the desired test procedures. The examples provided in this application note include tests and measurements with an actual solar inverter test setup, one of the more common applications for which regenerative power sources are used.

Regenerative Operation of an AC Power Source

The most common operating mode for an AC power source is to provide controlled power to electrical products. In this mode, the power source simply replaces utility-supplied AC line power, whether 120V-60Hz "North American type" power, 220/230V-50Hz used in most of Asia, South America and Europe, or 100V-50/60Hz used in Japan. The external power source provides the advantage of being able to precisely control the voltage amplitude, frequency and anomalous conditions such as distortion, dips, sags, interruptions, spikes and other typical power quality issues. Utility line power in most industrialized nations typically offers distortion levels of 3–5 percent with voltage fluctuations and dips easily exceeding 10 percent on an almost daily basis. For this reason, power sources like AMETEK's MX Series are widely used for testing electrical products in a controlled environment.

Regenerative Mode Operation

Power sources used in product testing are programmed either manually or by computer to produce the voltage levels, distortions, dips and interrupts that end products normally experience while operating off utility line power. In addition to these so-called immunity tests to evaluate a product's ability to withstand common public supply disturbances, AC power sources are also used to measure emissions or other potential disturbances that a product may produce. In such cases it is imperative that a source of clean power be used so that the test product's "disturbance contribution" can be accurately characterized. In either scenario, the product usually consumes power, that is, the source supplies power only but is not designed to receive power back, as is the case with regenerative systems.

Operating in Regenerative Mode, AMETEK's MX Series is capable of accepting power returning from any connected equipment. This power return can be a short-term event, as from an electric motor or other reactive load shut down. It can

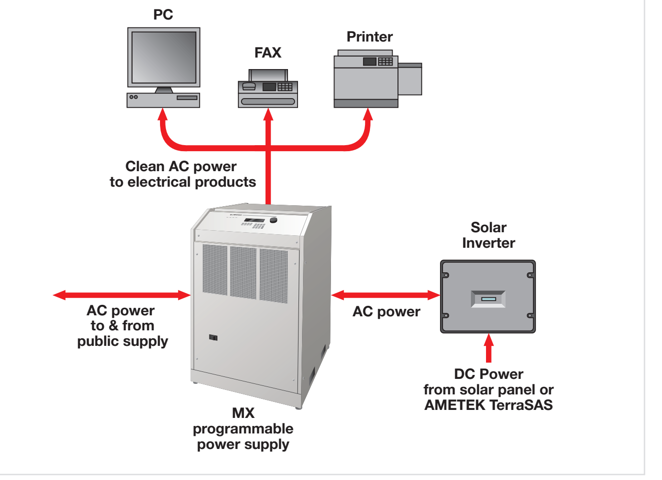

Figure 1. The MX Series power source can deliver power to and receive power from a solar inverter.

also be a semi-permanent condition, such as a solar power or wind power-based inverter supplying power back to the source. The power can come back continuously, intermittently or even during only part of each half AC cycle. If a solar inverter produces enough power, it can feed power continuously back to the source. If, on the other hand, the power level is insufficient to cover the load demand, the direction of power flow can change dynamically, even on a half cycle by half cycle basis. A regenerative power source that accepts power provided by an inverter is able to transfer this power back to the utility grid, as illustrated in Figure 1.

Generally, only switch-mode AC power sources are capable of transferring power back to the public supply. A so-called linear power source, acting as a high-power amplifier, will simply dissipate the returned power in the output stage. In other words, a linear power source performs like a load and converts the returned power into thermal energy. When this condition exists in a laboratory or production-line environment, the amount of heat produced typically requires an equal amount of cooling. In other words, the losses from a linear source are actually twice the amount of power that the inverter returns to the power source. With a regenerative power source, the power is actually returned to the utility grid with minimal loss. So, when a solar inverter is connected to the AC circuit, it supplies power to the load and also to the power source – the AMETEK MX in this case – which in turn sends the excess power back into the public supply in a controlled fashion. The MX is indeed capable of dynamic, bidirectional energy flow.

The Solar Inverter Test Example

Figure 2 illustrates the test setup that was used to acquire the data displayed in the screen captures and graphs that follow. The parameter settings of the SNK (Regenerative Mode) option will be explained in greater detail during an examination of several key characteristics required by power sources used for solar inverter test applications. And, because this process is substantially more complex than simply accepting returning power, this application note will make no attempt to include a comprehensive discussion of all solar inverter testing topics. For example, using the MX Series' SNK option has nothing to do with emulating solar irradiation patterns, emulating non-linear loads or inverter efficiency testing.

The solar inverter shown in Figure 2 employs a phase-to-phase 240V-60Hz configuration connecting to an MX45-3Pi with SNK option. Essentially a 240V delta (no neutral) configuration, this

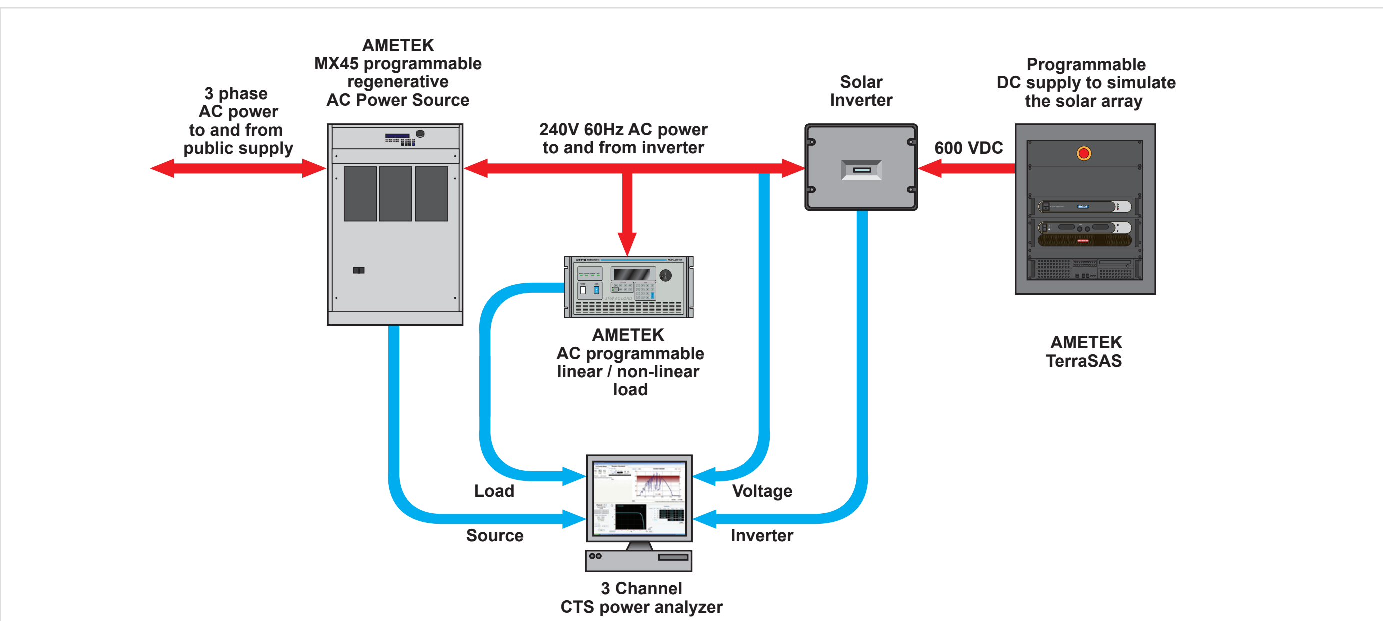

Figure 2: Inverter test setup to illustrate the Regenerative Mode of the Ametek MX Series

operating mode—sometimes called the "stinger mode" in US systems—provides measurements not unlike those obtained from European or Asian 220/230V-50Hz single-phase systems. This similarity allows the use of general data and eliminates the need for duplicate screens for various worldwide power systems referenced in this application note. As Figure 2 shows, power flow is measured in each of the three legs. However, when the inverter is not powered or synchronized to the 240V AC from the MX45-3Pi, power is supplied only from the MX to the load. When the inverter receives power from the DC source (or from a solar panel) it comes on line, synchronizes and begins to supply power. In this example, a 3kW inverter is used. If the HFC-II load setting is less than 3kW, the inverter supplies the excess power to the MX, which in turn sends the power back onto the public utility grid, as simulated by the AMETEK MX Series programmable power source.

The initial state of the above test setup is shown in Figure 4, just after DC power is applied to the inverter. The MX45 supplies 1261.6 Watts, of which 1260.9W goes to the load and just 0.3W to the inverter as it synchronizes to the 240V-60Hz line—a process that can take several minutes. The remaining 0.4W dissipates in the wiring and in a current shunt placed in series with the load. As the upper graph in Figure 3 indicates, the current flow (black line) combining the linear and non-linear loads remains in phase with voltage (green). This graph represents the measurement of the "left leg" extending from the MX to the interconnect point shown in Figure 2. The middle graph in Figure 3 combines the measurement of the "down leg" to the load (red line) and the current in the "right leg" – i.e., the current to/from the inverter (blue line).

The lower graph in Figure 3 shows the voltage spectrum, but the display is easily switched to display the current spectrum (up to 5kHz in this case) of either the source, load or inverter.

As the inverter synchronizes to 240V-60Hz, it injects about 0.8A of current that alternately leads a little more and lags a little less than 90 degrees, resulting in –23 Watts and +23W of power. These two conditions are shown in Figure 4.

Once synchronized and online, the inverter output gradually increases from zero to 3045 Watts, a process that takes roughly 60 seconds after DC power is applied. As Figure 5 shows, the transition from zero to 3044W, however, takes only about seven seconds. Figure 5 also illustrates the inverter coming online with the MX45 source smoothly transitioning from delivering load power to accepting the excess power from the inverter.

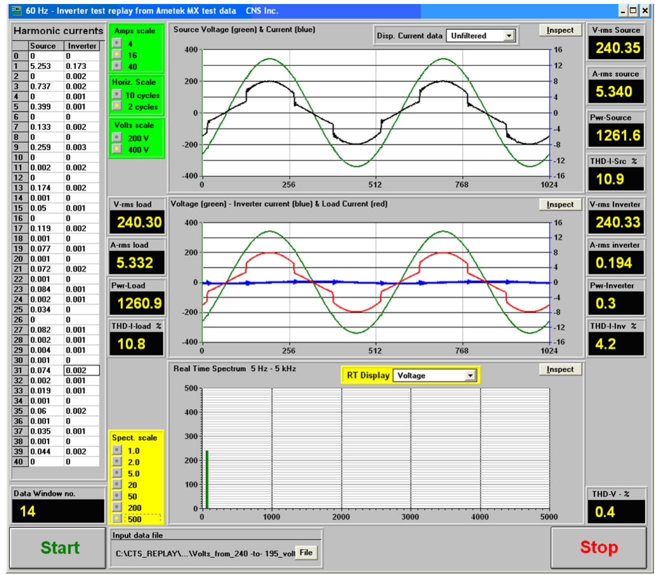

Figure 3: The initial condition shows the MX supplying power and the inverter not yet online.

Note that load power remains predictably constant during the transition, with Figure 6 showing the waveforms after the transition is completed. Source current flow is now 180 degrees out of phase (compare to Figure 3) with the voltage, a normal occurrence during a "negative power flow" condition. As ex-

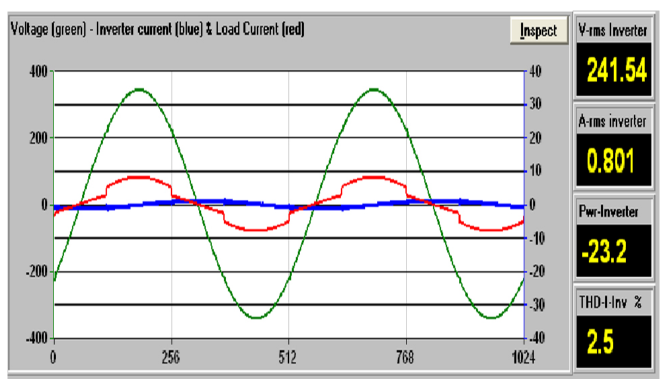

Figure 4: The inverter injects about 0.8A with a phase angle around 90 degrees, resulting in power being dissipated (-23W) and then delivered at about +23W.

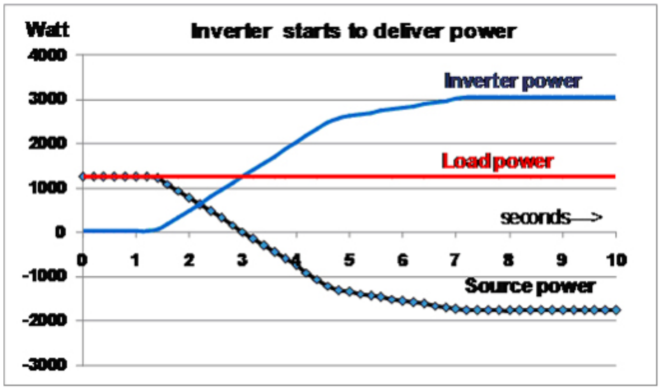

Figure 5: The inverter comes on-line and gradually increases its output to 3kW.

pected, the overall voltage level rises marginally as the inverter increases its output voltage slightly above the source voltage in order to deliver power to both the load and to the source (utility line power).

Thus far, the ability of the power source to function smoothly as a regenerative system has been demonstrated. Now, the additional features of the MX programmable power source with the SNK option will be reviewed.

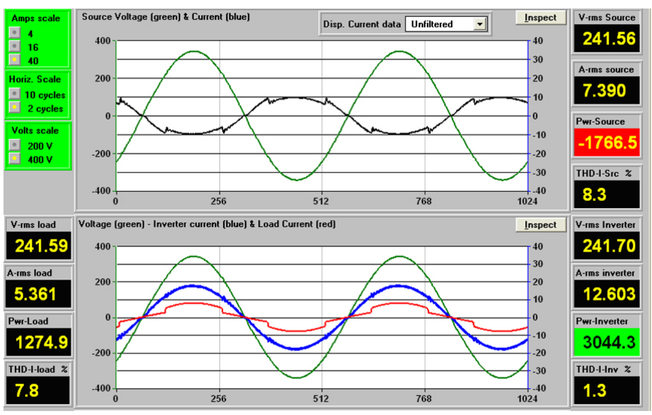

Figure 6: The inverter is on-line at 3044.3 Watts and supplies 1766.5W back to the MX.

Figure 7 illustrates the Regenerate Control screen display of the various user-settable values defined as follows:

Undervoltage — Lowest voltage that the source will default to in the event of an over-current condition;

REGENERATE CONTROL			
	STATE = ON		
UNDER VOLT=	212.0 V	dFREQ =	0.45 Hz
OVER VOLT =	263.0 V	DELAY =	5.000 S
PREVIOUS SCREEN		CURR =	8.0 A

Figure 7: Front-panel display of the MX with Regenerate Control parameter setup screen

Overvoltage — Highest voltage threshold before the source forces the inverter off-line;

Delta Frequency — Frequency change made by the source to force the inverter off-line;

Delay — Time that the source will take between over-current and each of the steps in the above actions;

Current Limit — Maximum current the inverter is permitted to inject into the source;

State — Regenerate state selectable by user for either "ON" or "OFF" operation

The Current Limit function in Regenerative Mode determines how much current the inverter will return to the source (public supply). This is different from the current limit that applies when the source delivers current. For example, the current limit that is delivered by the MX can be set to 40A, while the maximum current that the source permits to be returned to the MX could be set to 10A.

Effects of Programmed Parameters on an Inverter Test

Should the inverter exceed the preset Current Limit, the MX will increase its voltage level to the user-programmed Over Voltage limit. Note that this is exactly opposite the "normal" operating mode of a power source. Normally, when an over current condition is detected, the power source will reduce its voltage in an attempt to limit the current. So, if the inverter delivers too much current to the source, for example as the result of an overload condition, the MX gradually increases its voltage to the over voltage limit. If the duration of the over-current condition reaches the time threshold specified by the user-selected Delay function, the MX will change its frequency by the value of the "dFREQ" parameter—a condition that will usually force the inverter off-line. However, if this does not occur, the MX will lower its voltage after the "DELAY" number of seconds. If the over current condition still persists (i.e., the inverter has not gone off-line) the MX will open its output relay and then shut down. If the "dFREQ" parameter is set to "zero," the MX will skip the frequency step and transition directly from the Over Voltage value to the Under Voltage limit.

Finally, there is one more important difference relative to MX operation with Regenerate State selected ON. Normally, the MX programs its output voltage to "zero" before opening the output relay. In Regenerative Mode however, the output relay can be opened while the voltage is at the programmed level. This is to support the "balanced mode" anti-islanding test (see also Figure 12), in which the load is set to exactly absorb the output power of the inverter—thus balancing the inverter output and load demand. Then the MX output relay is opened, and the inverter has to detect that the "public supply" has been disconnected (for example the circuit breaker in the house has tripped).

The test inverter used to generate the graphs and figures in this application note demonstrated the following characteristics for the AC power side when operated in the 240V-60Hz "stinger" mode: AC voltage operating range: 211–264V; frequency

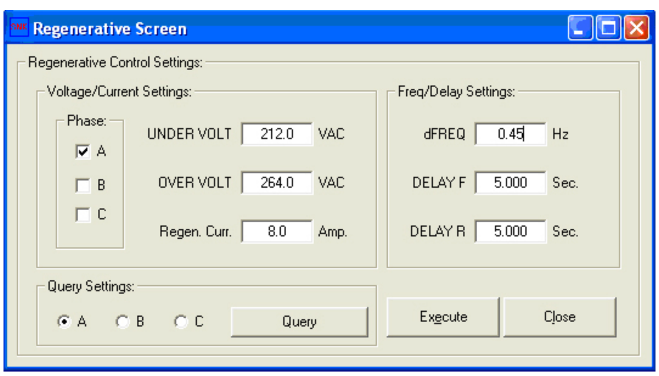

Figure 8: MXGUI screen indicating selected Regenerative Control parameters

range: 59.3–60.5Hz, max.; current: 13A @ 240V. Maximum distortion, DC input operating voltage range, efficiency, inrush current temperature and other inverter specifications outside the immediate purview of the Regenerative Control capabilities of the power source are discussed in detail in AMETEK data-sheet (http://www.elgar.com/products/MX_Series/downloads/California_Instruments_MX_Datasheet.pdf.)

PC-based MXGUI software (Figure 8) also supports the SNK option, allowing user access to various parameters that enable a broad series of inverter tests to be easily performed. For example, the user may use the Transient List function (Figure

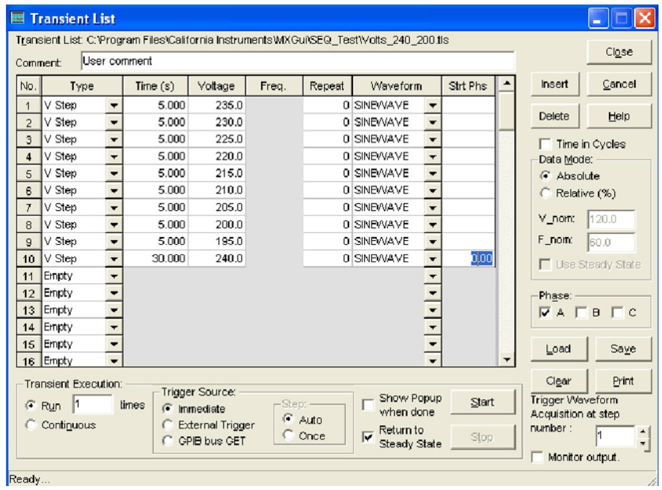

Figure 9: Transient List used to step the MX voltage

9) to produce the overall system behavior shown in Figure 10. The power source is programmed to step down from 240V to 195V in 5V increments, commencing around 20 seconds after the inverter has synchronized and come on line. The horizontal axis in Figure 10 is calibrated in increments of 0.2 seconds, such that 500 windows are measured over the 100-second duration of the test. As shown by the vertical axis, the load (red) increases from 5A to 8A about 25 seconds after data acquisition begins. Within a few seconds, the inverter (blue) comes online and starts to supply current. As the source voltage (green) steps lower, the inverter increases its current output to almost 15A. Once the voltage falls below the lower limit of 211V, the inverter goes offline and the source smoothly picks up the load current.

After completing the final step on the Transient List, the voltage level returns to 240V and the load current returns to its nominal 8A. Note that the source current falls from 8A to almost zero as the inverter comes online. Then, the inverter starts to feed back the excess power to the source, i.e. the source current

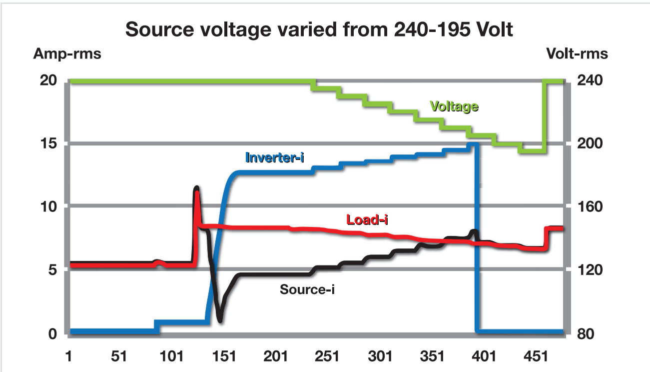

Figure 10: Current flow as the voltage steps in the Transient List are executed

increases, be it that it is 'negative' current flow, similar to what is shown in the waveforms in Fig. 6.

Using the MXGUI's Transient List function, the user may run other tests including, for example, the delta frequency test, in which the MX is programmed to step through a series of frequency changes. This test differs from 60Hz by increasing amounts, as shown in the following screen. Note that the inverter must remain on-line until the last step, when the frequency is changed to 60.6Hz, which exceeds the upper limit of 60.5Hz for the inverter that was tested in this setup.

Anti-islanding testing, another important performance measurement enabled by the SNK option, requires the power source to disconnect itself from the inverter and load while the load is perfectly balanced, as evidenced by no current flow to the source. Figure 12 illustrates the characteristic differences between unbalanced and balanced conditions. The left-hand image shows the inverter as an unbalanced load. In little more

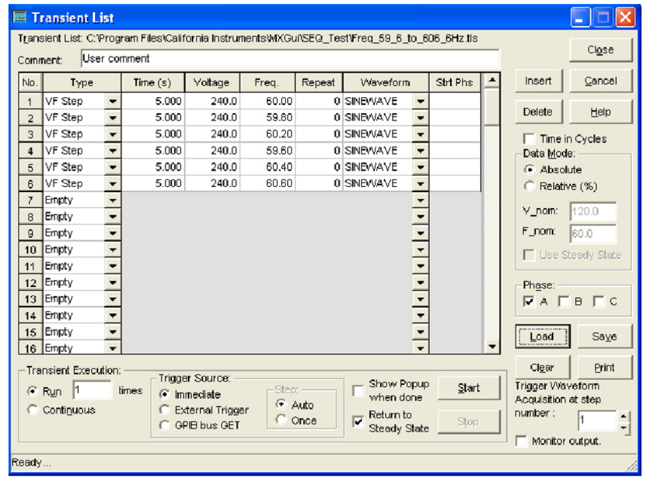

Figure 11: Illustration of an MX transient list stepping through a series of frequency changes to verify that the inverter disconnects from the public supply in the correct manner.

than half a cycle, the inverter disconnects after detecting that the power source (public supply) is no longer present. The right-hand image, however, shows how the inverter gradually increases its voltage (over the last 8-9 cycles) after the source has disconnected. Thus it only takes about 150ms for the inverter to detect an islanding mode and to shut down. Without the SNK option, the MX Series programmable power source will not open its output relay until it has programmed the voltage down to zero Volts. In "normal" mode, the MX does not allow this type of "balanced' anti-islanding test. Therefore, the SNK option should be specified whenever this type of test procedure is desired, since only the SNK option provides the user with a number of options for testing regenerative power systems.

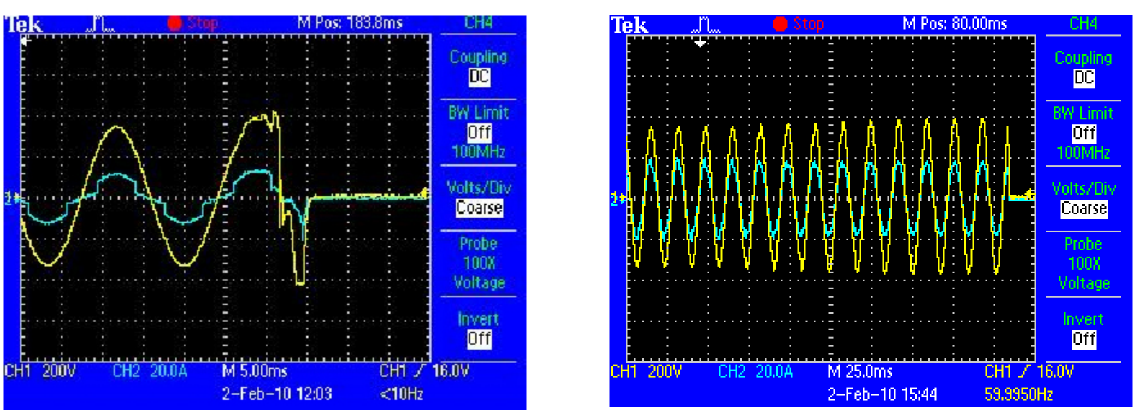

Figure 12: Inverter disconnecting with unbalanced (left) and balanced (right) load