THE MX SERIES SNK OPTION

USING THE AMETEK MX SERIES IN REGENERATIVE MODE

Introduction

The MX series power sources of Ametek can be used in either source or in regenerative mode. The SNK option settings determine how the MX "behaves" in regenerative mode, when the MX "receives power" back from the equipment that it is connected to. This application note describes the typical operation and settings of the MX in regenerative mode, using either the front panel or the MXGUI control software. The examples provided in this application note include measurements and tests with an actual solar inverter test setup, which is probably one of the more common applications that a regenerative power source is used in. In regenerative mode, the power source is said to "sink" power – as opposed to sourcing power, and thus the name for the SNK option.

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 the public supply system, whether it be 120 Volt 60 Hz "North American type" power, 220/230 – 50 Hz used in most of Asia, South America and Europe, or 100 V 50/60 Hz for Japan. The advantage of a power source is that one can closely control the voltage with either minimal, or controlled distortion levels. The public supply system in most industrialized nations has typical distortion levels of 3 – 5 %, and voltage fluctuations and dips can easily be in excess of 10 %, on an almost daily basis. Therefore power sources are commonly used to test electrical products in a controlled environment.

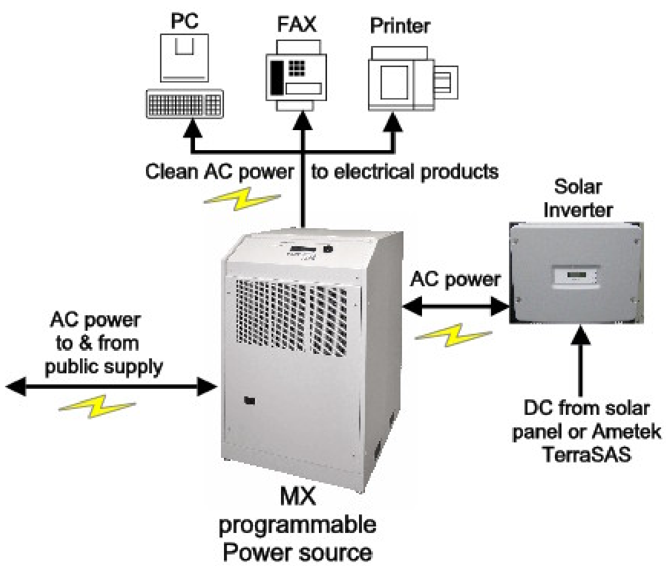

Figure 1 - Power source that can deliver power and accept power from a solar inverter

In product testing, the power source is programmed, either manually or by computer, to produce the voltage levels, distortions, as well as dips and interrupts, that the product can expect to see when it is operated from the public supply. These are so called immunity tests, i.e. tests to make sure that the products "survive" common public supply disturbances. AC power sources are also used to measure emissions, i.e. potential disturbances that the product may produce. In that case, one wants to have a "clean" power source, so that the "disturbance contribution" of the product can be measured. In both cases, the product usually "consumes" power, i.e. the source only supplies power, and does not have to be designed to receive power back, as is the case in regenerative systems.

In **regenerative mode**, the power source must accept power "coming back" from the equipment that is connected to it. This power coming back can be a short term event, for example from an electric motor or a reactive load being shut down, or it can be a semi-permanent operation, with a solar power or wind power based inverter supplying power back to the source. The power can come back continuously, or intermittently, or even during only part of each half AC cycle. If a solar inverter produces enough power, it can "feed" power back all the time. 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 coming back (from an inverter) is able to transfer this power back into the public supply. Figure 1 illustrates the concept.

Generally, only switch mode AC power sources have the ability to transfer power back to the public supply. So called linear power sources, basically a high power amplifier, will simply dissipate the “returned power” in the output stage. In other words, a linear power source just acts like a load and “transfers the returned power into thermal energy”. When this happens in a laboratory or production line environment, the amount of heat being produced is usually such that one needs an equal amount of cooling. In other words, the losses from a linear source are actually double the amount of power that the inverter sends to the power source. With a regenerative power source, the power is actually returned to the public supply, with minimal loss. So, when a solar inverter is connected to the AC circuit, it supplies power to the load and 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 to dynamically change the direction of the power flow.

The solar inverter test example

Figure 2 illustrates the test setup that was used to acquire the data that is used in the screen shots and graphs that follow. As we examine some key characteristics that a power source must possess when testing a solar inverter, the parameter settings of the SNK (Regenerate mode) option will be explained in more detail. Note that this application note doesn’t cover all solar inverter testing topics, as this is substantially more involved than just “accepting power coming back”. For example, using the SNK option of the MX has nothing to do with emulating solar irradiation patterns, emulating non-linear loads, or inverter efficiency testing. A more comprehensive overview of solar inverter testing is provided in another Ametek application note.

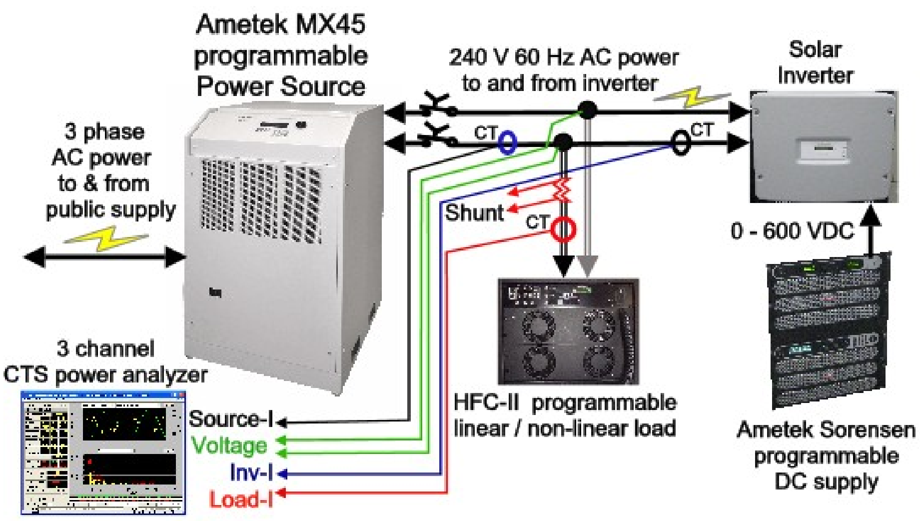

Figure 2 Inverter test setup to illustrate the Regenerative Mode of the MX

As is shown in Figure 2, the solar inverter is connected in a phase-to-phase 240 Volt – 60 Hz configuration to the MX45-3Pi with SNK option. This is basically a 240 V delta –no neutral– mode, sometimes also called “stinger mode” in US systems. Measurements in this operating mode are not unlike those obtained in a European or Asian 220/230V – 50 Hz single phase operation, which allows us to use the data in general, and thus avoid more or less duplicate screens for various worldwide power systems in this application note. The power flow is measured in each of the three legs as indicated in the figure. When the inverter is not powered, or not synchronized to the 240 Volt AC from the MX45-3Pi, there is only power supplied from the MX to the load. When the inverter receives DC power from the DC source (or from a solar panel) it comes on line, and after synchronizing, it starts to supply power. In this example, a 3 kWatt inverter is used. If the HFC-II load setting is less than 3 kWatt, the inverter supplies the excess power to the MX, which in turn sends the power back into the grid (i.e. into the public supply emulated by the MX).

In the screen shot shown in Figure 4, the initial state of the above test setup is shown, just after the DC power to the inverter is turned “on”. The MX45 supplies 1261.6 Watt, of which 1260.9 goes to the load, and just 0.3 Watt to the inverter, which is “receiving” a little power while it synchronizes to the 240 V – 60 Hz (which can take several minutes). The remaining 0.4 Watt is dissipated in the wiring and current shunt that is placed in series with the load. As can be seen in the top graph, the current flow (black line) is a combination of linear and non-linear load, but in-phase with the voltage (green). This top graph is the measurement in the “left leg” going from the MX to the interconnect point in Fig. 2. The middle graph combines the measurement in 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).

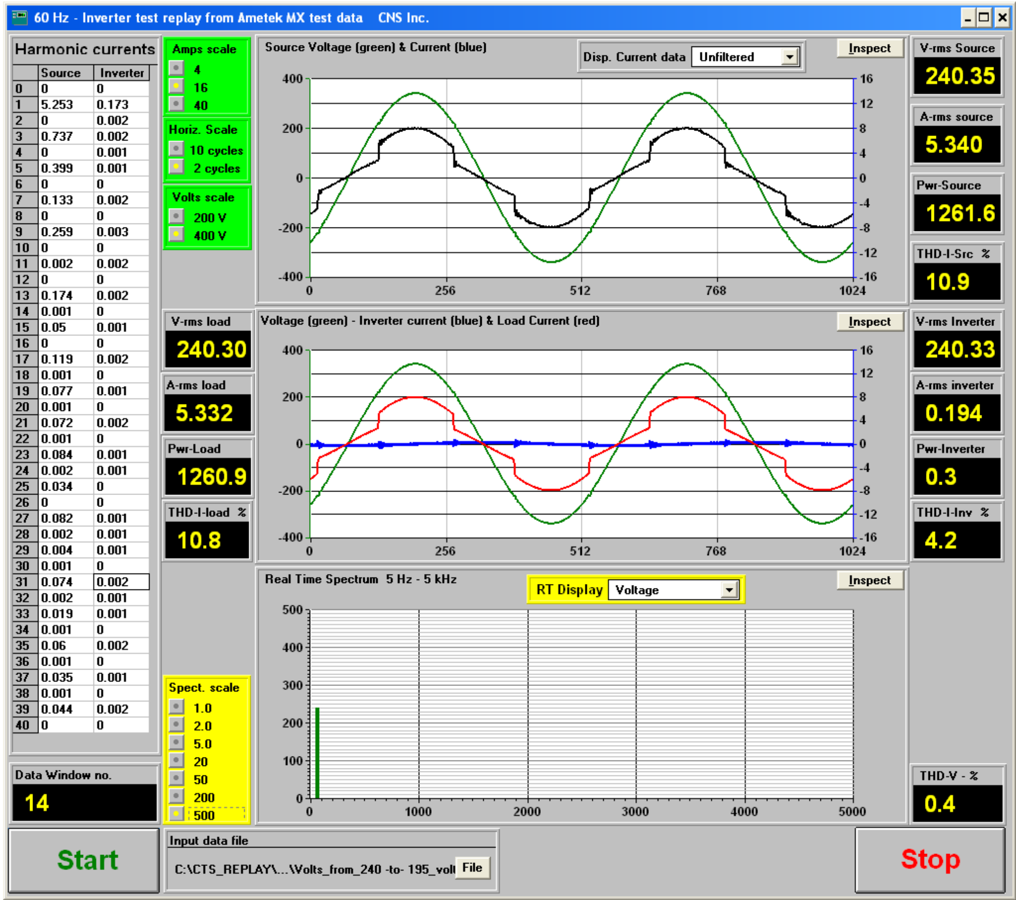

Figure 3 Initial condition with the MX supplying power and the inverter not yet on-line

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

As the inverter synchronizes to the 240 V – 60 Hz, it injects about 0.8 amp of current that is alternatively lagging a little more and a little less than 90 degrees, resulting in – 23 Watt and + 23 Watt of power. These two conditions are shown in Figure 4.

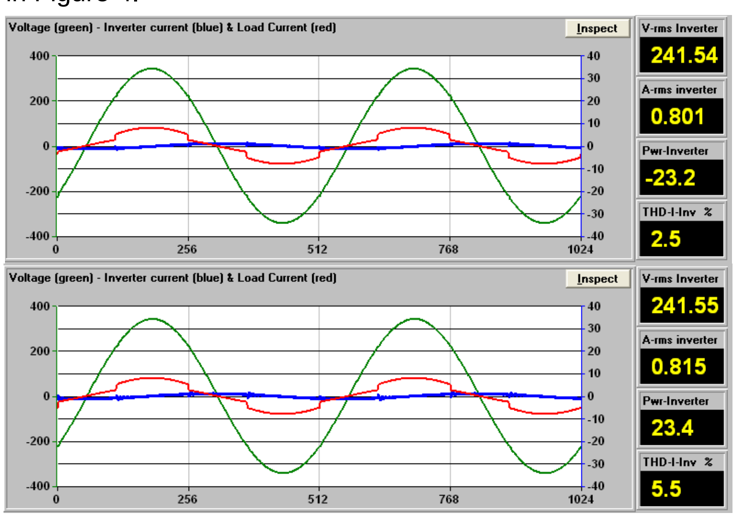

Figure 4

The inverter injects about 0.8 amp with a phase angle around 90 degrees, resulting in power being dissipated (- 23 Watt) and then delivered at about 23 Watt

Upon synchronizing, the inverter comes “on line” and gradually increases its output power from zero to 3045 Watt. The overall process takes about a minute after DC power is applied, and the transition from zero to 3044 Watt takes about 5 seconds. Figure 5 shows this transition as the inverter comes on-line, and the MX45 source smoothly transitions from delivering the load power to accepting the excess power from the inverter.

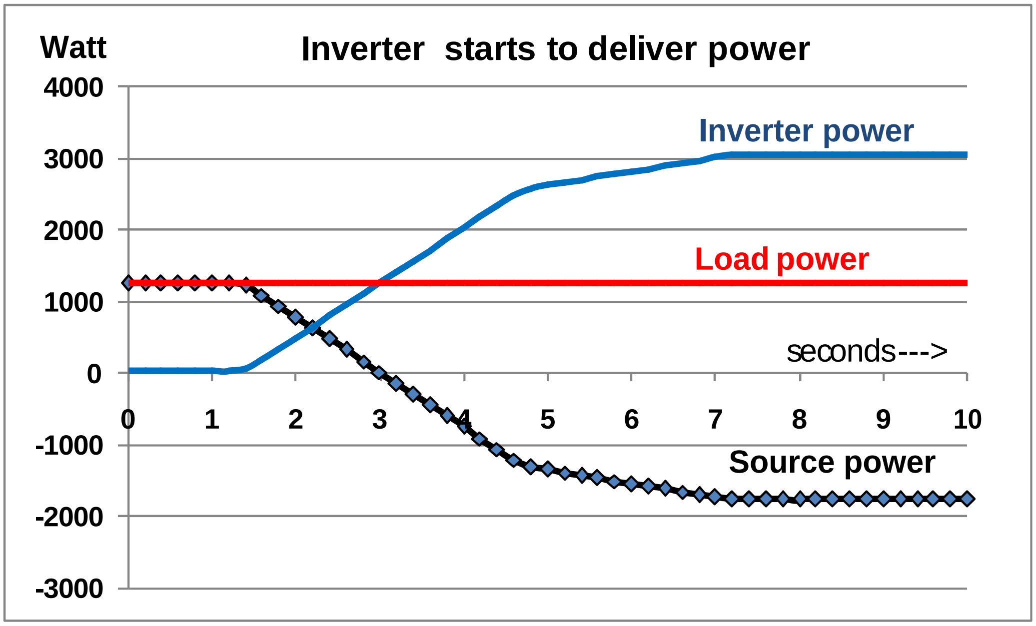

Figure 5 The inverter comes "on-line" and gradually increases its output to 3 kWatt

Note that the load power stays constant during the transition, as it should. Figure 6 (below) shows the waveforms after the transition is completed. The current flow in the source is now 180 degrees out of phase (compare this to Fig. 3) with the voltage, as one expects when there is "negative power flow". Note that the overall voltage level has gone up just a bit, which is also to be expected, as the inverter needs to increase its output voltage slightly above the source voltage, in order to deliver power to both the load and into the source/public supply.

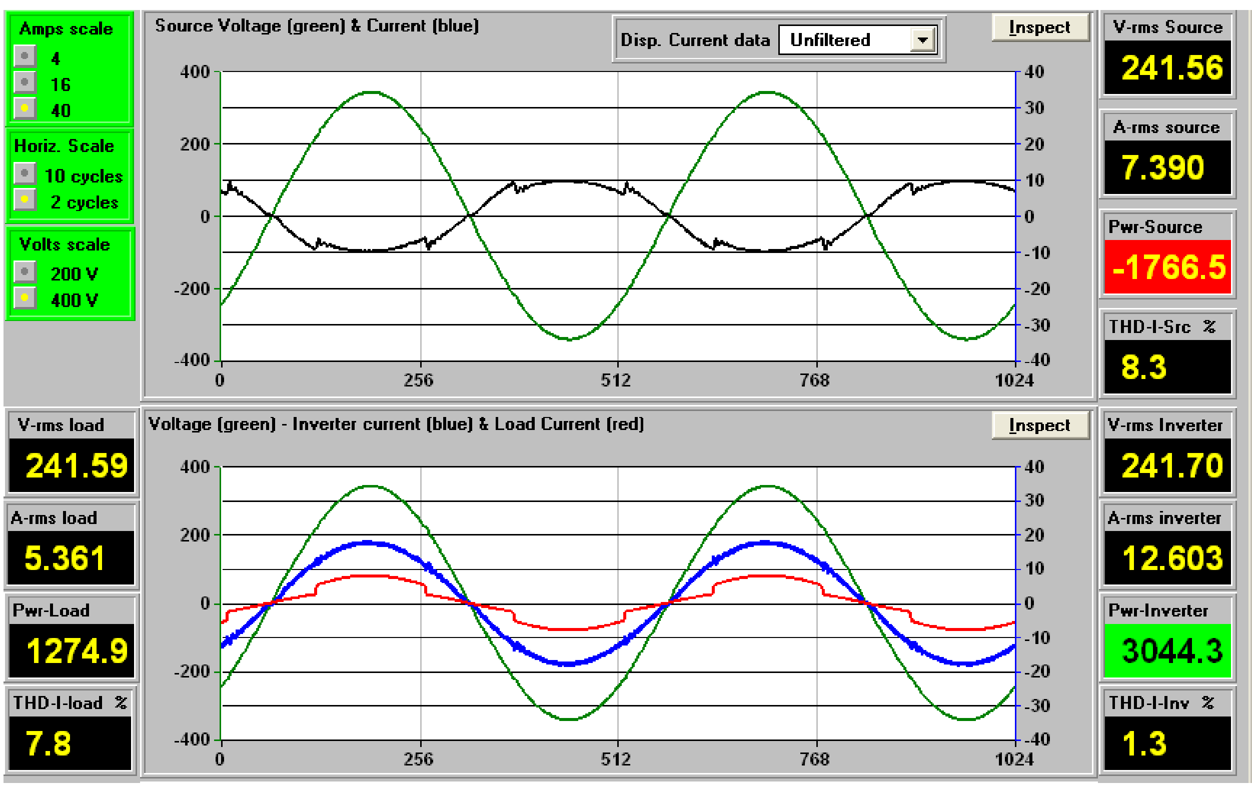

Figure 6 The inverter is "on-line" at 3044.3 Watt, and supplies 1766.5 Watt back to the MX

The SNK option features

Thus far, we have demonstrated the ability of the power source to function smoothly as a regenerative system. Now, we can review the additional features of the MX source with the SNK option. As the screen of the Regenerate Control shows, the user can set values for the following parameters;

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

Under voltage; the lowest voltage that the source will "move" to in case of over-current
Over voltage; the highest voltage that the source will "move" to in order to "force" an inverter "off-line"
delta Frequency; the frequency change that the source will make to force the inverter "off-line"
Delay; the time that the source will take between over-current and each of the steps in the above actions
Current Limit; the maximum current the inverter is permitted to inject into the source
Also, the user can select the Regenerate **State** to be either **"On"** or **"Off".**

The current limit in Regenerate mode determines how much current the inverter is permitted to send back into 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 40 amps, while the maximum current that the source permits to be **returned** to the MX could be set to 10 amp.

The parameters cause the following actions during an inverter test; In the event that the inverter exceeds the current limit, the MX will increase its voltage level – up to the user programmed "Over voltage" limit. Note that this is exactly opposite of 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 (i.e. could be overloaded) the MX gradually increases its voltage up to the over voltage limit. If the over-current condition persists for the amount of seconds specified by "DELAY", the MX will change its frequency by the amount of the "dFREQ" parameter. Generally, this will force the inverter "off-line", but if not, the MX will lower its voltage after the "DELAY" number of seconds. If the over current 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 directly go from the "over voltage' value to the "under voltage' limit..

Finally, there is one more important difference in the MX operation when the Regenerate State is ON. Normally, the MX will program its output voltage to "zero" before opening the output relay. In regenerate 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 this anti-islanding test, the load is set such that it exactly absorbs the output power of the inverter. Thus, the inverter output and load demand are balanced. 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 inverter that was tested in the process of generating the graphs and figures in this application note, has the following characteristics for the AC power side, when operated in the 240 V/60 Hz – stinger mode; AC voltage operating range 211 – 264 V, Frequency range 59.3 – 60.5 Hz, max. current 13 amp @ 240 volt. The inverter has additional specifications for other parameters, such as maximum distortion, DC input operating voltage range, efficiency, inrush current temperature etc. – but these go beyond the immediate description of the Regenerative Control capabilities of the power source, and will be discussed in detail in another Ametek application note.

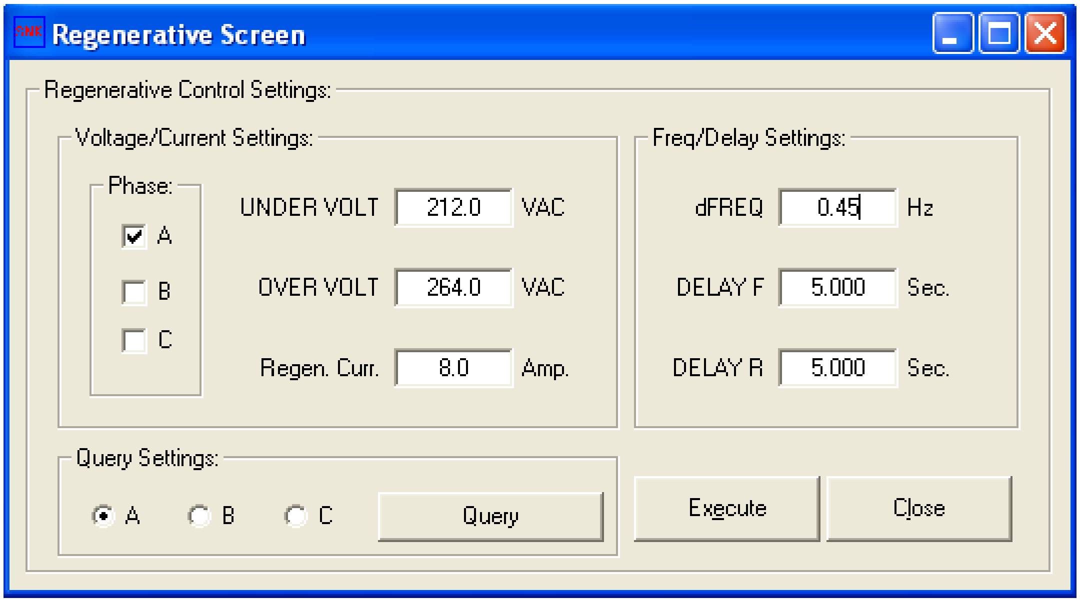

Figure 8   MXGUI screen to set the Regenerative Control parameters

The MXGUI software (see Figure 8) also supports the SNK option, and the user has access to the various parameters via the PC. Using the Regenerate parameters, one can perform a series of inverter tests easily. For example, the user may use the transient list capability as illustrated below in Figure 9, which results in an overall system behavior as shown in the graph of Figure 10. The power source is programmed to “step’ from 240 volt to 195 volt in 5 volt steps. This “stepping” is started ~ 20 seconds after the inverter has synchronized as has come on line. The horizontal axis in Fig. 10 is given in 0.2 sec measurement windows i.e. the overall duration of this test was about 100 seconds (500 windows).The load is increased from 5 to 8 amp (left axis) about 25 seconds after the data acquisition is started. Within a few seconds, the inverter comes on-line, and starts to supply current. As the source voltage steps lower, the inverter increases its current up to almost 15 amp. As the voltage falls below the minimum limit of 211 Volt for this inverter, the inverter goes off-line, and the source smoothly takes over the load current.

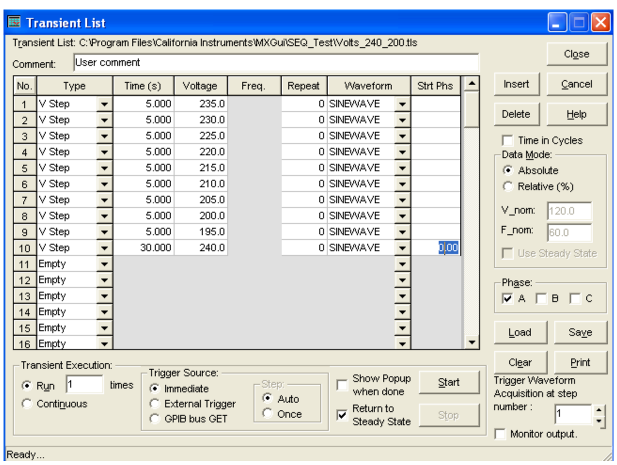

Figure 9 Transient list to step the MX voltage

After the transient list steps through its last step, the voltage returns to 240 volt, and the load current thus returns to its nominal 8 amp. Note that the source current falls from 8 amp to almost zero, as the inverter comes on-line. Then, the inverter starts to feed back the excess power into the source, i.e. the source current increases, be it that it is ‘negative’ current flow, similar to what is shown in the waveforms in Fig. 6.

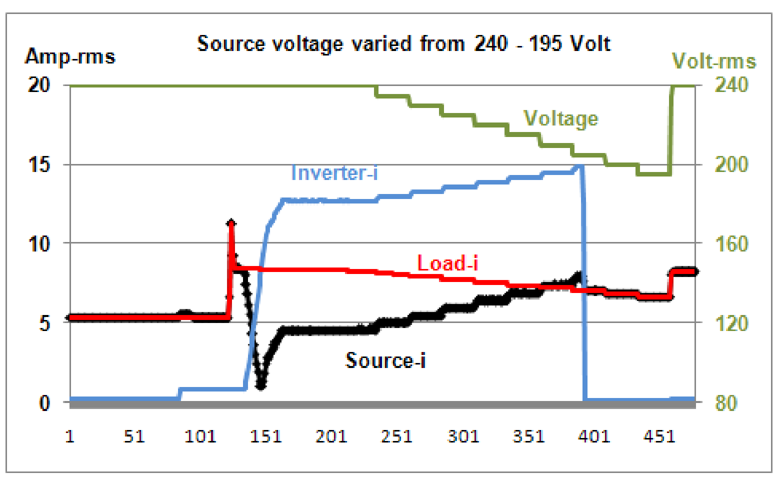

Figure 10 – Current flow as the voltage steps in the transient list are executed

The user may run other tests, using the transient list of the MXGUI. An example is the delta frequency test, where the MX is programmed to step through a series of frequency changes that differ from 60 Hz by increasing amounts, as shown in the screen shot below. The inverter needs to stay “on-line” until the last step, when the frequency is changed to 60.6 Hz, which exceeds the upper limit of 60.5 Hz for the inverter that was tested in this setup.

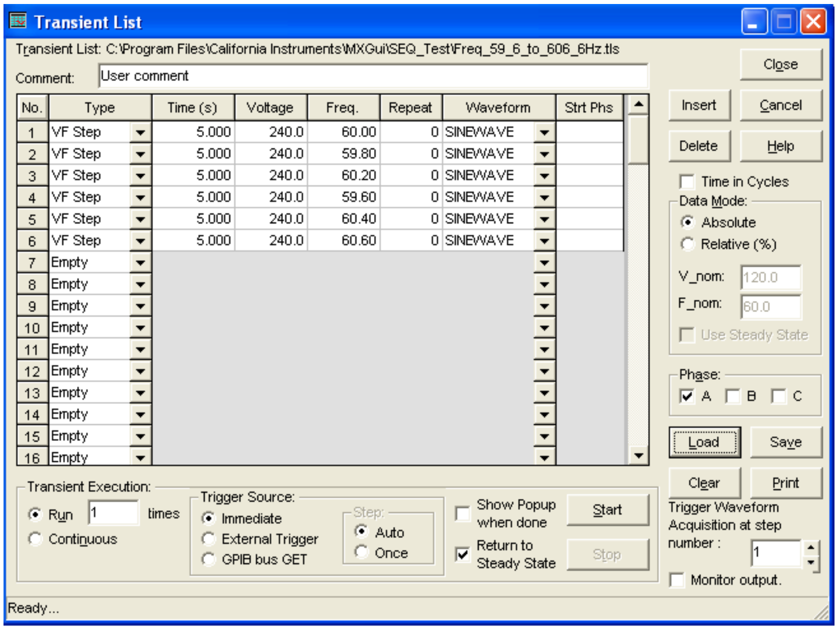

Figure 11

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

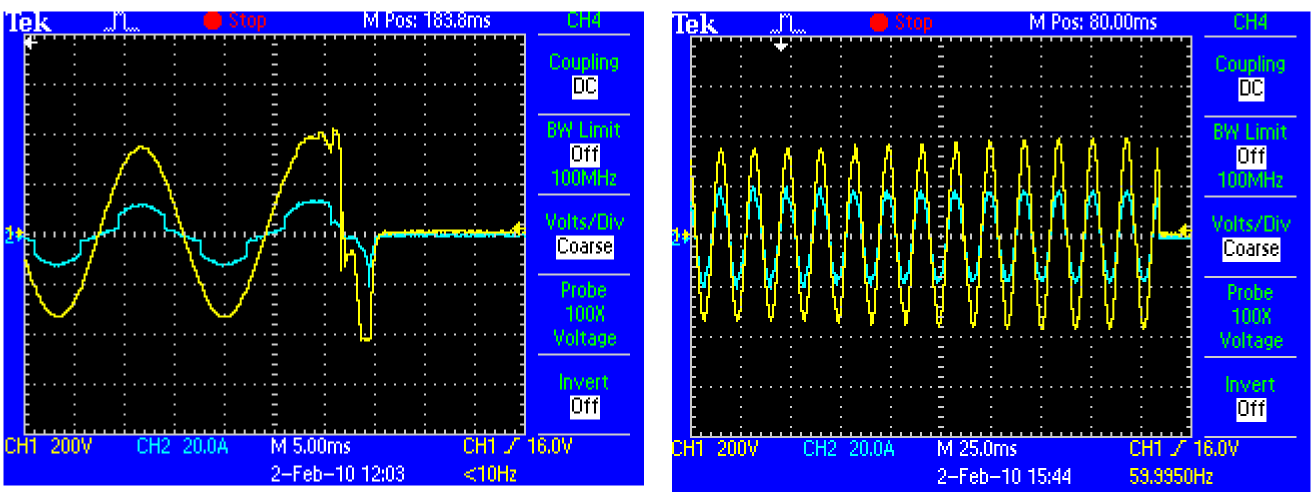

Figure 12 Inverter disconnecting with unbalanced (left picture) and balanced (right side) load

Another test, which requires the SNK option, is one of the classical anti-islanding tests. This requires the power source to disconnect itself from the inverter and load, while the load is perfectly balanced, i.e. there is no current flow into the source. To illustrate the difference in behavior between an unbalanced and a balanced condition, the picture on the left side in Figure 12 shows the inverter action with an unbalanced load. It takes only a little more than a half cycle for the inverter to detect that the power source (public supply) is no longer present, and to disconnect. The picture on the right hand side however, shows how the inverter gradually increases its voltage (over the last 8-9 cycles) after the source has disconnected. So, it takes about 150 ms before the inverter detects that it is in an “islanding” mode, and then it shuts down. Without the SNK option, the MX will not open its output relay until it has programmed the voltage down to “0” volt. So, in “normal” mode, the MX does not allow this type of “balanced’ anti-islanding test described above.

In conclusion, the SNK option gives the user a number of options to test regenerative power systems.