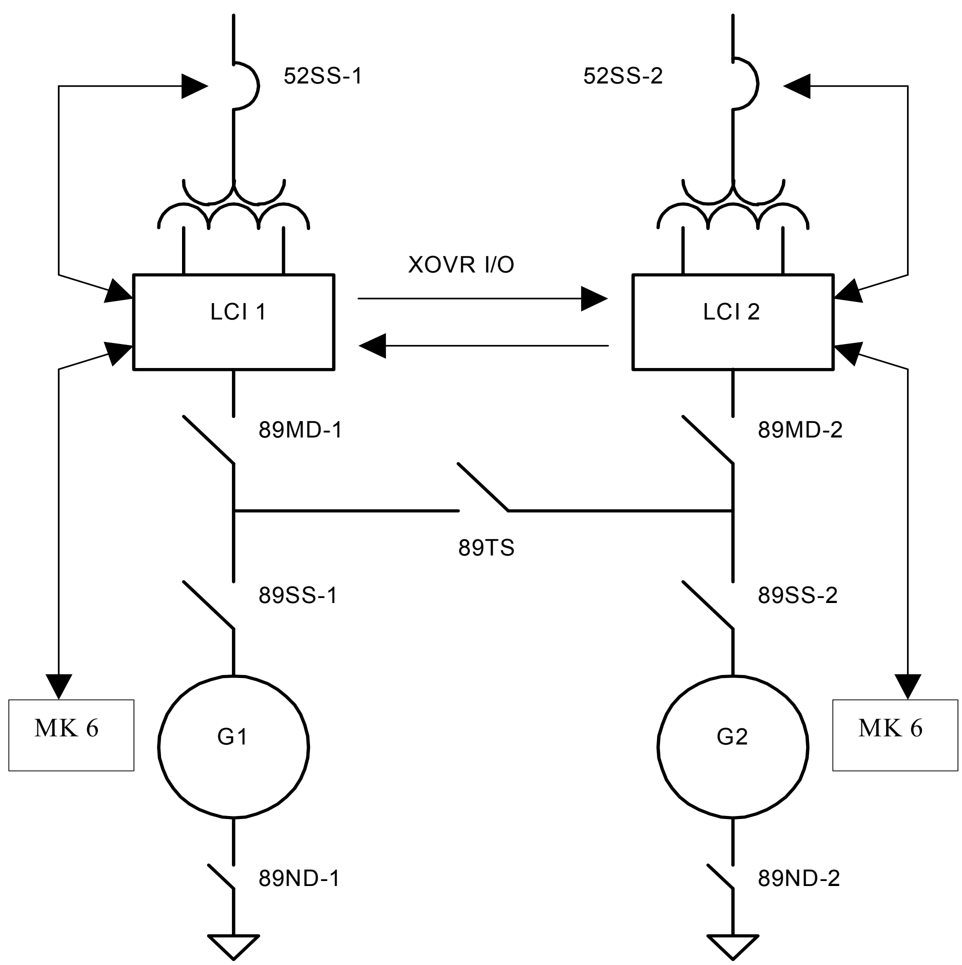
LCI Static Starter System Checkout and Operation with EX2000 and Mark VI

One of the first things to do when beginning checkout of a Static Starter system is to find out just what site configuration you have. The number of gas turbines on site as well as the number of LCIs that are part of the system will determine just what the overall system will look like. There are a number of possibilities as to how a system is configured. We have fairly simple systems with one LCI and one or two gas turbines as well as systems with multiple gas turbines and multiple LCIs. High voltage disconnect switches are used to connect the generators to the LCIs and control of these switches could be done in a Mark VI or in an LCI. There is also the question of whether a site has a crossover capability where an LCI has the capability to start units it is not normally connected to, or when an LCI fails and another has to do the work that LCI normally would do. The last consideration that affects how the control is distributed and how units start up is concerned with the LCI breaker 52SS and how that breaker is controlled as an LCI prepares to start one of the gas turbines.

The type of control hardware in the LCI will also affect how the checkout of the LCI and the system is done. One LCI control we see now on Mark VI sites has a UC2000 and OC2000 in the LCI with Genius I/O blocks connected to the UC2000. Another LCI control has a UC2000 with VersaMax PLC and AFE Datapanel for I/O and display purposes. So far it appears that LCIs with UC2000, OC2000 and Genius I/O are used on sites where there is crossover capability built into the UC2000 software while LCIs with UC2000, VersaMax and an AFE Datapanel system are used on sites with one or more units and no software crossover or on sites that have multiple units and an external hardwired crossover control panel. Also of interest is whether or not the LCI has hardware and software in it to control LCI breaker 52SS, which will change how some of the high voltage disconnect switches operate. Until recently control of breaker 52SS was either manually done or controlled by the Mark VI, but now almost all units will have 52SS control circuitry in the LCI. The only LCIs that may not be controlling 52SS are on sites with an external hardwired crossover control panel or on sites with multiple source breakers that could energize high voltage to the LCI instead of just one breaker.

Consider a site configured as in the figure below. There are two gas turbine units and two LCIs, as well as two 89MD (Main Disconnect) switches and one 89TS (Tie Switch) switch. Also shown are the high voltage isolation transformer and circuit breaker 52SS for each LCI as well as 89SS and 89ND for each generator. We have seen 89SS and 89ND before and they operate the same now as they did in earlier systems. The LCIs in this system have UC2000, OC2000 and Genius I/O in them since this site has a software crossover scheme. Each LCI communicates to a Mark VI by Ethernet and also has certain I/O signals hardwired between the Mark VI and LCI. Ethernet communication in this case is used mostly to transmit specific alarm and fault information from the LCI to the Mark VI. If there is no control in the LCI for closing breaker 52SS, then when an LCI is powered up the 89MD associated with that LCI closes and the LCI is in “normal” mode. If there is control in the LCI for closing 52SS, then the LCI will be in “normal” mode after power up but 89MD will not close until later when

52SS is closed. The main benefit in this system is that with the addition of 89TS we have the ability to connect either LCI to either generator as long as we can set up 89TS and the 89MD switches in the appropriate position. The control of 89TS and each 89MD is done in the LCIs and not in either Mark VI. Also seen in the figure below is an attempt to show the ability to transfer I/O from one LCI to another, as shown by the "XOVR I/O" which is the "crossover I/O" capability of this system. As stated each LCI communicates with a Mark VI by hardwired signals wired to Genius I/O modules and when requested this I/O in one LCI can be "transferred" to the other LCI so that this other LCI can now communicate with the Mark VI connected to this transferred I/O. In this way LCI1 can communicate with the Mark VI on unit 2 and can start that unit once the 89MDs and 89TS are set up properly and once the XOVR I/O is transferred to LCI1. Similarly LCI2 could be used to start unit1. The crossover request that starts this transfer comes from a Mark VI as in input to the LCI that will be used to replace the failed LCI. If for example a crossover request has been sent to LCI1, then LCI1 would "transfer" I/O from LCI 2 back to LCI1, and also close 89TS. LCI1 is now in "crossover" mode instead of "normal" mode. 89MD-1 would already be closed if there were no control of 52SS from LCI1 and at this time 89MD-2 would be opened to isolate LCI2. If control of 52SS is initiated from the LCI, then neither 89MD would be closed at this time. When the Mark VI on unit 2 initiates a start it effectively is communicating with LCI1 and this LCI will start unit 2.



Section 1 - Preparation for Starting a Gas Turbine Unit with an LCI

Before attempting to start a gas turbine unit for the first time with an LCI there are a number of control circuits that must be checked and verified. Certainly all the testing of the LCI itself must be completed, but there are interface circuits between the LCI and other major elements of the system that also need to be looked at and verified in preparation for a start attempt. The preparation we will discuss here in Section 1 is how to complete the checkout of the interface between the LCI and other devices in the system, including signals between the LCI and Mark VI, EX2000 and LCI breaker 52SS.

LCI Contact Input String from Isolation Transformer Control

One of the control circuits to be checked is from the transformer that supplies high voltage to the LCI. The transformer has a group of protective devices mounted on it that will detect various types of trouble in the transformer. The devices that are used in this circuit are shown on the one line diagram for this system, and may include an oil temperature alarm, winding temperature alarm, liquid level alarm and vacuum or pressure alarms. This external circuit is made up of normally closed contacts in series and is shown in the LCI elementary as a contact input on sheet 1EA in LCIs with Genius I/O and on sheet 1EK in LCIs with VersaMax. When one of the contacts in this circuit opens it will generate an alarm in the LCI, and the LCI will display a "Transformer NOK" message on the display device, which indicates that the transformer is not OK. This alarm does not shut down the LCI if it occurs while the LCI is running nor does it keep the LCI from starting a unit.

LCI Contact Input String from Circuit Breaker 52SS

Another device that interfaces with the LCI is circuit breaker 52SS that energizes the transformer that supplies high voltage to the LCI. The one line diagram for the system will show a contact input to the LCI from this breaker that is called switchgear status, which is shown in the LCI elementary on sheet 1EK. This input is made up of multiple contacts, one of which is a normally open contact from breaker 52SS that indicates the status of the breaker – if the contact is open the breaker is open and if the contact is closed the breaker is closed. A contact of this type is called an "a" contact. The normally closed contacts in series with this "a" contact, called "pretrip" contacts, are there for protection of the LCI and will open when some other device is about to open breaker 52SS. Any device that could open 52SS must have a contact is this string that opens when the command is given to open breaker 52SS. This will indicate to the LCI that something else is about to trip the high voltage, since this input will open milliseconds before the breaker opens and high voltage is interrupted. This indication that the high voltage is about to be tripped gives the LCI enough time to stop firing any SCRs in preparation for loss of high voltage. This shutting down of SCR firing before loss of high voltage could save SCRs from failing in the source bridges if they are firing while the high voltage is being interrupted. Usually, all of the devices on breaker 52SS that could trip the breaker are connected to an 86 lockout relay that will trip the breaker. This 86 lockout relay has a contact in series with the switchgear status input to the LCI instead on a contact from each individual device on the breaker. There are other devices that could also have pretrip contacts in this circuit if they will trip breaker 52SS. A transformer 86 device will sometimes have a contact in this string to trip the breaker on fault pressure in the transformer.

Another contact in this string could come from the Mark VI. If the Mark VI closes 52SS as part of the Static Starter Connect sequence and trips the breaker after the LCI has started the unit as part of the Static Starter Disconnect Sequence, then the Mark VI should have a pretrip contact in this switchgear status string as well. A dry contact output from the Mark VI would have to be wired into this circuit, and the Mark VI would have to energize this output at the same time that it energizes the output contact that trips the 52SS breaker. On jobs where the Mark VI commands the LCI to close 52SS there is no need to have a Mark VI contact in series with the status contact from the 52SS breaker.

When the Mark VI is closing the 52SS breaker as part of the start sequence or when the LCI is closing 52SS when commanded to by the Mark VI, the LCI will have to indicate that it is "Ready to Start" before there is high voltage on the LCI. To accomplish this, a constant in the LCI called SQOPT1 has to be changed. Set bit 11 to a "1" in SQOPT1 to implement this change. This change will add 2048 to the decimal value already in SQOPT1. For example, if there is a value of 47024 in SQOPT1 then the LCI will not be "Ready to Start" until high voltage is applied to the LCI. If 2048 is added to SQOPT1 so that the value is now 49072 then the LCI will indicate "Ready to Start" before high voltage is energized. This will allow the Mark VI to begin the start sequence since the LCI is indicating that it is "Ready to Start". Without this change to SQOPT1, the unit could not start.

LCI Output Contacts to Breaker 52SS Control Circuits

There are three possible ways to control 52SS – manually close the breaker and leave it closed, close and trip by command from the Mark VI, and close and trip from the LCI when commanded by the Mark VI. There will be added software and hardware to implement closing 52SS from the LCI that were not in previous versions of the LCI control.

In an LCI where 52SS is operated manually or operated by the Mark VI, there are two contacts from a relay in the LCI that are wired into the control circuit for breaker 52SS. This relay is called SWGR and is shown in the LCI elementary on sheet 1EC. One of these contacts is normally open and is wired into the trip circuit of 52SS to trip the breaker when this contact closes. The other is a normally closed contact that is wired into the close circuit of 52SS so that it permits closing the breaker if the contact is closed and inhibits closing the breaker if the contact is open. This SWGR relay is normally not energized, and will energize when the LCI has to trip breaker 52SS. This relay circuit must be tested since this is the only way the LCI can interrupt high voltage to the source bridges if a fault occurs in the LCI. First, verify that the SWGR relay will be energized when the SRCFLT contact is closed as shown on sheet 1EC. This can be tested by jumpering the output terminals for the SRCFLT relay contact, TB5 terminals 4 and 6 on the DDTB board shown on sheet 1EL. Next, verify that Genius output SBFT shown on sheet 1EC will also energize the SWGR relay by forcing output SBFT to a “1” in the UC2000 program. Once high voltage is energized, operate the SWGR relay again by forcing output SBFT to a “1” to verify that breaker 52SS trips. With the SWGR relay still energized, try to close breaker 52SS either locally from a control switch on the breaker cubicle door or by forcing signal L52SSXC to a “1” in the Mark VI, if it is capable of closing the breaker. If the breaker does not close then the close inhibit contact of the SWGR relay is operating properly.

In an LCI where 52SS close and trip commands come from the LCI when commanded by the Mark VI, the situation is slightly different. In this case there are two relays in the LCI called SWGRT and SWGRC that have contacts in breaker 52SS control circuits. These relays are shown on sheet 1EC in LCIs with Genius I/O and on sheet 1DB in LCIs with VersaMax. Relay SWGRT operates in a similar fashion to relay SWGR mentioned above, in that it has a normally open contact in breaker 52SS trip circuit that will open 52SS when relay SWGRT is energized. Relay SWGRC has a normally open contact in breaker 52SS close circuit that will close 52SS when SWGRC is energized. There is also a normally closed SWGRT contact in series with the SWGRC contact in the close circuit so that 52SS will not get a close command from SWGRC if SWGRT is energized.

Normal operation of breaker 52SS starts with a command from the Mark VI to the LCI. When signal LSS_PWR from the Mark VI changes to a “1”, LCI input LSSPWR becomes a “1”. If there are no faults in the LCI, output SBCLS will energize which will energize relay SWGRC that in turn closes breaker 52SS. Once a gas turbine start has been completed the LCI shuts down which drops out “Runx” in the LCI. This will open breaker 52SS by energizing output SBTRP that energizes relay SWGRT that in turn will trip breaker 52SS.

One more input of interest here is the LCI input TRPINH shown on sheet 1EA in LCIs with Genius I/O and on sheet 1EK in LCIs with VersaMax. This input is shown as a MULTST input from an external location. This input will inhibit the trip of breaker 52SS at the completion of a start so the breaker and LCI are ready to make another start of some other unit. This “multi-start” input would only be used when another start is to be made right away. At this time there is no Mark VI output that generates this signal, but it could come from the customer’s DCS system.

During a normal start in a system that includes the software crossover function, once 52SS closes this initiates a close command to 89MD. Once the LCI knows that both 52SS and 89MD are closed it energizes output CONNCT on sheet 1EC in LCIs with Genius I/O and on sheet 1DB in LCIs with VersaMax. This output goes to the Mark VI and is called LSS_CONNECT there, where it indicates that the LCI connection is complete.

LCI Run Command Contact Inputs from Mark VI

There are two digital inputs to the LCI from a Mark VI that command the LCI to run. These inputs are identified as Start/Run Request and Torque Request. These inputs may be hardwired or they may be sent over Ethernet as EGD (Ethernet Global Data) signals depending on the type of system you have. Typically on a single LCI system one signal would be hardwired and one signal would be on EGD, and in a system with two LCIs and a software crossover scheme they both would be hardwired. The hardwired inputs are shown in the LCI elementary on sheet 1EA or 1DD in LCIs with Genius I/O (depending on whether the LCI has software crossover or not) and they are split up in LCIs with VersaMax, with Start/Run Request shown on sheet 1DA and Torque Request shown on sheet 1EK. Both signals would be hardwired in an LCI with VersaMax if the site had an external hardwired crossover panel.

On single turbine sites these signals are called RUNRQ and TORQ, and on multi-turbine sites or sites with crossover they are numbered so they become RUNRQ1 and TORQ1 for unit1 and so on. Both of these inputs must be a "1" for the LCI to run. The only time these two inputs are not both "1" while the LCI is running is when the unit is coasting from purge speed down to firing speed. The Torque Request is dropped out at this time while Start/Run Request is still picked up. These signals can be tested by forcing the appropriate Mark VI output and then monitoring the appropriate LCI signal. The Mark VI signal that generates the Start/Run Request is L4SSRUN and the signal that generates the Torque Request is L4SSTORQ. Force L4SSRUN to a "1" and verify that the Start/Run Request input RUNQ1 changes to a "1". Then force L4SSRUN to a "0" and verify that RUNQ1 changes to a "0". Force L4SSTORQ to a "1" and verify that Torque Request input TORQ1 changes to a "1". Then force L4SSTORQ to a "0" and verify that TORQ1 changes to a "0".

LCI Speed Reference Input from Mark VI

There is one speed reference input into the LCI from a Mark VI. If this is hardwired it is shown in the LCI elementary as a 4 to 20 ma speed reference input on sheet 1DC in LCIs with Genius I/O and software crossover and on sheet 1EM in LCIs with VersaMax (notice that this input actually comes into the DDTB board). This analog input is called SREF1 in the UC2000 program. The scaling of this input is 0% speed reference equals 4 ma input and 100% speed reference equals 20 ma input. This analog input can be tested by forcing certain coils in the Mark VI program, then checking the analog input at the input block and in the UC2000 program to see that it is at the proper level. With no outputs forced in the Mark VI this analog input should be 4 ma, which correlates to 0% speed reference. This can be checked with a voltmeter, since there is a 100 ohm resistor connected internally across the terminals of the Genius input block and a resistor of approximately 200 ohms across the DDTB board input. Assume that we are calculating voltages based on the Genius input block signal in the examples below. Connect a voltmeter across terminals 11(+) and 12(-) and there should be 0.4 volts dc reading, which indicates there is 4 ma flowing into the input. Monitor SREF1 in the UC2000 program and it should be approximately zero counts. If Mark VI signal

L83SS_FULSPD is forced to a “1” this changes the Mark VI speed reference output to 100% which can be monitored by observing SS_REF_OUT in the Mark VI. With 100% speed reference the analog input should be 20 ma and the voltage across the analog input terminals should be 2.00 volts dc. Observe signal SREF1 in the UC2000 program and you should see approximately 20000 counts. It is also possible to check this input value when the Mark VI is sending Purge speed reference and Firing speed reference. First check in the Mark VI for the value of the Purge speed constant K83SS_PURGE. Force signal L83SS_PURGE to a “1” to send the Purge speed reference to the LCI. If the Purge speed constant is 25%, for example, then the analog reference input would be (20-4)*0.25+4 = 8 ma. The voltage across terminals 11 and 12 of the analog input module would be 8*100 = 0.8 volts dc. The value in SREF1 should be approximately 5000 counts. Check in the Mark VI for the value of the Firing speed constant K83SS_FIRE. Force signal L83SS_FIRE to a “1” to send the Firing speed reference to the LCI. If the Firing speed constant is 14.5%, for example, then the analog reference input would be (20-4)*0.145+4 = 6.32 ma. The voltage across terminals 11 and 12 of the analog input module would be 6.32*100 = 0.63 volts dc. The value in SREF1 should be approximately 2900 counts. It should be noted that there are no adjustments in the LCI for these values – the LCI uses whatever the Mark VI sends. The only value that could cause us any problems during the starting sequence is the value the LCI calculates for firing speed, and we will discuss that in Section 2 of this document where the starting sequence is described in detail.

If the speed reference from the Mark VI is sent over EGD it is not shown in the drawings at all. The UC2000 program receives this reference on the EGD page as it is sent out of the Mark VI with the signal name G1\SS_REF_OUT. The UC2000 program moves this reference to LCI1\SPDREF1. Monitor this signal to see how many counts are received as each speed point is forced.

Note – if this reference is not connected or if the Mark VI is sending 0 ma you should see approximately –5000 counts in signal LCI1\SPDREF1 in the UC2000 program. You would also see –5000 counts here if the speed reference wiring is crossed with the wrong polarity into the Analog Input block.

LCI Operating Status Contact Outputs to Mark VI

There are four signals sent to the Mark VI that indicate the operating status of the LCI. These are known in the Mark VI as Ready to Start, Running, Fault and Alarm. They may be sent over EGD or as hardwired outputs of the LCI to Mark VI inputs.

If these signals are hardwired they will be shown in the LCI elementary as outputs on sheet 1EC or on sheet 1DG (depending on whether the LCI has software crossover or not) or on sheet 1DE in LCIs with VersaMax. These contacts are connected to Mark VI inputs and are powered by the Mark VI 125 v dc power supply (+62.5 volts dc to ground on wire #107) that is connected to one side of each of these contacts. When there is more than one Mark VI directly connected to the LCI there are sets of these outputs reserved for and connected to each Mark VI.

The first of these output signals from the LCI is SSRDY, which is the Ready to Start input in the Mark VI. This signal is called L3SS_RS in the Mark VI, and can be tested by forcing signal SSRDY to a “1” in the LCI and verifying that signal L3SS_RS changes to a “1” in the Mark VI. Then force signal SSRDY to a “0” and verify that signal L3SS_RS is a “0” in the Mark VI.

The next output signal from the LCI is SSRUN, which is the Running input in the Mark VI. This signal is called L4SS_RUN in the Mark VI, and can be tested by forcing signal SSRUN to a “1” in the LCI and verifying that signal L4SS_RUN changes to a “1” in the Mark VI. Then force signal SSRUN to a “0” and verify that signal L4SS_RUN is a “0” in the Mark VI.

The next output signal from the LCI is NCHFLT, which is the Fault input to the Mark VI. This signal is called L4SST in the Mark VI but it has also been called L94SS in some earlier units. This LCI output is actually a “No Fault” signal because the output is a “1” when there is no fault in the LCI. When the LCI faults this output drops out, or changes to a value of “0”. However, the Mark VI uses this L4SST signal in such a way that it expects a “1” for an LCI fault. Therefore, the Mark VI has to invert this contact input so that a “0” in the LCI (fault condition) becomes a “1” in the Mark VI (fault condition). This can be tested by forcing signal NCHFLT to a “0” in the LCI and verifying that signal L4SST changes to a “1” in the Mark VI. Then force signal NCHFLT to a “1” and verify that signal L4SST is a “0” in the Mark VI. When L4SST is a “1” the Mark VI does not automatically generate an alarm on the Mark VI alarm screen, since this contact is used in the Mark VI program and does not just simply generate an alarm message.

The last of these output signals from the LCI is ALARM, which is the Alarm input in the Mark VI. This signal is called L30SS in the Mark VI, and can be tested by forcing signal ALARM to a “1” in the LCI and verifying that signal L30SS changes to a “1” in the Mark VI. Then force signal ALARM to a “0” and verify that signal L30SS is a “0” in the Mark VI. When L30SS becomes a “1” the Mark VI generates an alarm message on the Mark VI alarm screen.

When EGD is used to transmit these signals only three of them will be on EGD and one will be hardwired. The NCHFLT signal has been the one signal that has been hardwired up to this point. Checkout of the EGD signals is essentially the same as for the hardwired signals as described above.

LCI Contact Output to the Generator Panel

There is another “No Fault” contact output from the LCI that is used in a circuit in the Generator Panel. This LCI contact output is shown in the LCI elementary on sheet 1EC or on sheet 1DJ in LCIs with Genius I/O (depending on whether the LCI has software crossover or not) and is shown on sheet 1EL in LCIs with VersaMax. When the LCI does not have a fault this contact is closed and when the LCI has a fault this contact opens up. This “No Fault” contact output is wired to the Generator Panel, where it usually shows up as a normally closed 94SS contact on sheet 4B of the Generator Panel elementary. There is a normally open 52GX contact wired in parallel with this 94SS contact, and then there are some contacts from other devices in the Generator Panel wired in series with these contacts. Contact 52GX is a contact from an auxiliary relay that follows the status of the generator breaker. When the generator breaker closes, 52GX picks up and closes the contact in parallel with 94SS. This contact string shown on sheet 4B is wired as an input to the EX2000 and is shown in the EX2000 elementary on sheet 10D, although all of the contacts in this string are not shown there. Under normal conditions all the contacts in this string are closed and relays K20 and K21 in the EX2000 are picked up. If any contact in this string opens up K20 and K21 drop out which causes a fault the EX2000. The 94SS contact is in this string so that the EX2000 can be shut down if the LCI faults while starting the unit. If the LCI faults contact 94SS opens up and the dropout of relays K20 and K21 will shut down the EX2000. This is done because the Mark VI may not issue a stop command to the EX2000 on an LCI fault and this is a way to guarantee that the EX2000 will be shut down if the LCI faults while starting a unit. The 52GX contact is in parallel with 94SS so that once the LCI has completed the start and the generator breaker is closed the LCI no longer has the ability to shut down the EX2000.

LCI Analog Output Reference to EX2000

There is one analog output signal from the LCI that is connected to an EX2000 to control generator excitation level during a start. This output is shown in the LCI elementary on sheet 1EL as an output from the DDTB board. If there is only one gas turbine on a site, the analog output is directly connected as an input to the PTCT card of each core in the EX2000. If there are multiple units directly connected to an LCI, then this analog output is connected to each EX2000 through relay contacts of relays mounted in the LCI. These relays are shown on sheet 1DF in LCIs with Genius I/O and are shown on sheet 1DE in LCIs with VersaMax. The appropriate relay will energize and connect the LCI analog output to an EX2000 based on which Mark VI is attempting a start using this LCI. If a software crossover system exists in the LCIs on site there will also be wired connections to and from the other LCI shown on sheets 1EL and 1DF. This LCI analog output is used as a voltage reference to the EX2000 manual regulator and the level of this reference will determine the amount of excitation generated by the EX2000. Since an EX2000 does not normally utilize an external reference, all EX2000 exciters used on units started with an LCI have specific software that scales this reference and connects it to the manual regulator. A signal called Static Start Mode is sent to the EX2000 from the Mark VI to tell the EX2000 to use this external reference as the excitation reference. The Static Start Mode signal also forces the EX2000 into Manual Regulator mode, where it will stay as long as Static Start Mode is energized in the Mark VI. The EX2000 is put in Static Start Mode by signal L4EXSS from the Mark VI.

This LCI analog output signal is variable from 0 to 10 volts dc, and the voltage level of this output will determine the excitation output voltage of the EX2000. The scaling of this reference is shown on sheet 1EL and is defined as 0 volts dc output equals 0 volts dc excitation and 10 volts dc output equals 1.25*VFNL (hot) dc excitation. VFNL is defined as Volts Field No Load and the designation (hot) is used to show that the field resistance used in the calculation of VFNL is the field resistance at 125 degrees C. For a typical generator used with an LCI, the hot field resistance is 0.199 ohms and Amperes Field No Load (AFNL) is 577 amperes. Using these numbers VFNL would be 114.8 volts dc. So, if the LCI analog output was at 10 volts dc, the EX2000 output should be 1.25*114.8 = 143.5 volts dc if the scaling in the EX2000 was correct. This scaling can be checked during the installation and checkout phase of the LCI startup, and can be done with the EX2000 in simulation mode or with a dummy load connected. Put the LCI in User Test #8 to adjust the level of this analog output. Don't forget to force the appropriate LCI output to get the reference to the appropriate EX2000. Vary the output level in User Test #8 while the EX2000 is running and record EX2000 output voltage at various reference levels. Make sure that the scaling is correct as calculated with the specific data for that generator.

Just because this analog output is capable putting out 10 volts dc doesn't mean that it does this during normal start attempts. The analog output level during a start attempt is set by a constant in the LCI and will be approximately 6 volts dc. With the numbers used in our example, a 6 volts dc reference would generate approximately 86 field volts. If the generator field temperature was at 125 degrees C, then field current would be 86/0.199 = 432 amperes. This would be the lowest field current we would possibly expect, since at normal operating temperatures the field resistance is lower and field current would be higher. With the generator field at ambient temperature levels the field current could reach approximately 500 amperes. Once the LCI starts a unit and reaches Self Commutated mode, a flux regulator in the LCI adjusts this analog reference to regulate the flux level in the generator, which is being used as a motor. If the flux regulator needs to it will lower this reference to regulate 1 PU flux in the air gap of the motor. When the turbine is fired and the unit is accelerating towards top speed, this analog reference is lowered as speed increases above approximately 30% in order to maintain constant armature voltage out of the LCI to the motor.

Section 2 – Detailed Description of Sequence of Events that Occur During a Successful Start

One of the most critical moments during a gas turbine startup is when a normal start is attempted for the first time. One of the major concerns is that this is the first time that all the major parts of the electrical control system have to work together as one coordinated control system. However we sometimes find units that will not start the first time, and finding the cause of a failure to start can be a difficult and time-consuming situation. This control system is distributed between the Mark VI, LCI and EX2000 which can add to the difficulty of finding the cause of a problem. Hopefully, the following description of the sequence of events that occurs during an LCI startup of a gas turbine should help increase understanding of the process and may help to reduce troubleshooting time during starting problems. Refer to the Mark VI program as well as drawings for the LCI, EX2000 and Generator Terminal Enclosure to see the actual control information for a specific site. Also, the one line diagram will show the specific configuration of your system including all disconnect switches such as 89ND, 89SS, 89MD and 89TS.

- Before attempting a start, every effort should be made to complete the checkout of the Mark VI, LCI and EX2000. All systems should be operating normally with no faults or alarms present and all temporary jumpers should be eliminated.
- The generator coolers should be operating normally with proper water flow.
- The unit must be on turning gear with the motor control selected for Auto.
- Cooling water must be flowing through the “external” side of the LCI water-to-water heat exchanger or overheating will occur in the LCI.
- If breaker 52SS is manually operated, it must be closed at this time to apply high voltage to the LCI. Once high voltage to the LCI is energized, the LCI sends the “Ready to Start” signal to the Mark VI. This signal is called L3SS_RS in the Mark VI. If the Mark VI closes breaker 52SS during the start sequence or if the Mark VI tells the LCI to close 52SS during the start sequence, a constant in the LCI must be modified so that the LCI will send the “Ready to Start” signal to the Mark VI before 52SS is closed. This modification is discussed in Section 1 of this document.
- The EX2000 will indicate to the Mark VI that it is ready to start if the EX2000 core that is selected on the OC2000 does not have a trip fault. This EX2000 Ready to Start signal is called L3EX_RS in the Mark VI.
- If the EX2000 source breaker is manually operated, it must be closed at this time to apply AC voltage to the EX2000. If the Mark VI controls this breaker, it will be closed during the EX2000 connect sequence.
- After a master reset is initiated the Mark VI should be ready to attempt a start as long as all Mark VI systems are operating normally.
- Once a Master Reset is initiated in the Mark VI, signal L4EXSS will be a “1” as long as the Mark VI is Ready to Start and no turbine shutdown signal is present. Signal L4EXSS puts the EX2000 in Static Start Mode, which will allow the EX2000 output voltage to be controlled by an external reference from the LCI. The EX2000 is forced into Manual Regulator at this time and stays in Manual as long as L4EXSS is energized. The “SSMODE” light on the exciter OC2000 is now lit, as is the Manual regulator light.
- Once the EX2000 is in Static Start Mode, it sends a signal back to the Mark VI telling it that the EX2000 is in Static Start Mode. This signal becomes LSS_ACTV in the Mark VI. It is used in the Mark VI as a permissive for starting the EX2000 and LCI, and nothing else in the start sequence could be completed if this signal is not a “1” in the Mark VI.
- The Mark VI has an extensive start check system that will indicate that the system is ready to start. Included in this system are fault signals from the LCI and EX2000, but surprisingly the EX2000 and LCI ready to start signals have not always been part of this system. So, make sure that L3SS_RS is a “1” indicating that the LCI is ready to start and that L3EX_RS is a “1” indicating that the EX2000 is ready to start.
- A normal start can now be initiated in the Mark VI. The first thing that the Mark VI does is to check the operation of the emergency lube oil and seal oil pumps.

- If the Mark VI closes the breaker that supplies AC voltage to the EX2000 it will be closed now during the EX2000 connect sequence. Once this sequence is complete signal L3EX_SSCON in the Mark VI becomes a "1" which indicates Connect Sequence Complete for the EX2000.
- The Mark VI then issues a start command to the EX2000 by energizing output L4EX_START. This sends the start command over EGD to the EX2000. The EX2000 starts and the output contactors in the EX2000 close. With AC voltage on the EX2000 and the output contactors closed, the EX2000 generates a signal back to the Mark VI that indicates the EX2000 is running. This signal becomes L4EX_SS in the Mark VI. The EX2000 has no output at this time since the excitation reference from the LCI is still zero. It should be noted that if the Mark VI controls the breaker that applies AC voltage to the EX2000, it must close before the start command is sent to the EX2000 or the EX2000 will not tell the Mark VI it is running.
- At the same time that the Mark VI is starting the EX2000 it also begins the connect sequence for the LCI by energizing signal L4SS. L4SS is known as the "Static Starter Master Start Permissive" and it must be a "1" in the Mark VI before anything can be done to connect the LCI to the generator in preparation for running the unit.
- Now that L4SS is a "1" the connect sequence begins as L83SS_CON becomes a "1". If the Mark VI controls breaker 52SS, L83SS_CON energizes output L52SSXC which then closes breaker 52SS. When breaker 52SS closes it sends a status contact back to the Mark VI called L52SS that indicates the breaker is closed. If the Mark VI tells the LCI to close breaker 52SS, then once L83SS_CON becomes a "1" the Mark VI sends a signal called LSS_PWR to the LCI. Once the LCI receives this signal it energizes LCI output SBCLS which energizes relay SWGRC which closes 52SS. Also, LCI output MDCC will be energized to close main disconnect switch 89MD at this time if this system has crossover capability. Once both 52SS and 89MD are closed the LCI sends a signal to the Mark VI called LSS_CONNECT that tells the Mark VI that the breaker and disconnect switch have closed.
- If the Mark VI controls breaker 52SS, at the same time as breaker 52SS is being closed, neutral disconnect switch 89ND is commanded to open when the Mark VI energizes coil L89NDXO. When the disconnect switch opens it sends a status contact back to the Mark VI called L89NDO that indicates the switch is open. If the Mark VI tells the LCI to close breaker 52SS, once the Mark VI receives signal LSS_CONNECT from the LCI then signal L69SS_CON will become a "1" and neutral disconnect switch 89ND will be commanded to open when the Mark VI energizes signal L89NDXO.
- Once switch 89ND is open, LCI disconnect switch 89SS can then be closed by energizing signal L89SSXC in the Mark VI. When the disconnect switch closes it sends a status contact back to the Mark VI called L89SSC that indicates the switch is closed. When there are multiple units on a site there may be an inhibit contact in this rung that keeps this 89SS from closing if some other unit is being started by the LCI. This would keep more than one 89SS on site from closing at the same time and attempting to connect multiple

generators to one LCI. It is also possible to have hardwired interlocking between units to interlock the 89SS switches so that only one 89SS can be closed at any time.

- After 52SS closes, 89ND opens, 89SS closes and the EX2000 Connect Sequence Complete signal L3EX_SSCON is a "1" then signal L3SS_CON becomes a "1" in the Mark VI indicating that the connect sequence is complete. Without this signal becoming a "1" there is no chance of starting the LCI.
- Once L3SS_CON becomes a "1", the next thing that happens is the Mark VI sends some information to the LCI. First, signal L83SS_PURGE becomes a "1" in the Mark VI. This does two things. One is it sends the purge speed reference to the LCI (see signal SS_REF_OUT in the Mark VI) and the other is it energizes Mark VI signals L4SSRUN and L4SSTORQ that together command the LCI to run.
- As soon as L4SSRUN and L4SSTORQ each become a "1", the LCI initiates its internal Run mode. This allows the LCI to send an analog reference out to the EX2000 so that the EX2000 will energize the generator field. This reference is determined by a constant in the LCI and will be about 6 volts dc. As we saw in our example in Section 1 of this document, this would allow the field to build up to about 86 volts dc. The LCI also changes its operating mode to "run", and the "Ready to Start" signal L3SS_RS that the LCI was sending to the Mark VI changes to a "0" and the LCI "Running" signal L4SS_RUN changes to a "1" in the Mark VI.
- Even though Run has picked up, the LCI is still not trying to turn the motor. The LCI is waiting for the field current to build up before it will try to accelerate the motor. Since the field has a large inductance it takes some time for the field current to build up after the voltage is applied to the field. The amount of time that the LCI waits is set by a constant in the LCI and is typically about 14 seconds. At the end of this time field current will be approximately 500 amperes, depending on the temperature of the field. While the LCI is waiting for excitation to build up, the generator is actually generating a very low frequency voltage that the LCI is reading at the output terminals of the LCI since it is connected to the generator through 89SS. The LCI uses this voltage feedback to determine where the rotor poles are so that it can determine when to start firing the LCI.
- Once the wait is over for field current buildup, the LCI fires both source bridges and the load bridge so it can increase voltage and frequency to the motor to accelerate it towards purge speed. At this time the generator is acting like a motor and the LCI will control the acceleration rate of the motor as speed increases.
- When the motor speed reaches about 100 to 125 rpm, the LCI will activate a flux regulator that will adjust the analog output to the EX2000 so that it can regulate flux in the motor. Typically the reference to the EX2000 is slightly higher than it has to be during the initial start, and the regulator will start adjusting the reference to regulate flux. At this time the output current of the

EX2000 will be about 400 to 500 amperes and is being controlled by the flux regulator.

- The unit will continue to accelerate until it reaches purge speed, which is determined by the level of the speed reference sent to the LCI by the Mark VI. If the purge speed reference is 25% in the Mark VI, for example, the unit will accelerate to this speed and then stay at this speed. It should be noted that the LCI calculates the speed reference based on the milliamp level of this reference if it is sent in hardware and by the counts in SS_REF_OUT on EGD if it is sent by Ethernet, so if this reference is slightly low or high then speed will not be exactly 25%, but it should be very close.
- The unit will stay at this speed until the purge of the turbine and exhaust stack is complete. The amount of time spent purging the unit is determined by a timer in the Mark VI called L2TV, and may be as low as a few minutes for a simple cycle machine or up to 30 minutes for a combined cycle unit. When coil L2TV energizes the purge is complete and rung L83SS_FIRE picks up, which drops out rung L83SS_PURGE. This changes the LCI speed reference from purge to firing level, which is usually set at 14.5%. Also, this causes coil L4SSTORQ to drop out in the Mark VI since there is a speed contact L14HMZ in series with the closed L83SS_FIRE contact in this rung and the L14HMZ contact is open at this point. L14HMZ is a contact from a speed switch in the Mark VI that is open at this point and closes as speed decreases below 14%.
- When L4SSTORQ drops out the LCI loses its torque input signal. This causes the regulators in the LCI to “suicide” and the LCI output goes to zero. The analog reference to the EX2000 collapses to zero at this time. The LCI still indicates it is running but it is not producing any torque. The motor speed will decrease as the rotor begins to coast down.
- When the rotor coasts down to slightly below 14% speed, contact L14HMZ will close in the Mark VI and coil L4SSTORQ will energize which sends the torque input to the LCI. The LCI will start running the motor again and since the speed reference is at firing speed (14.5%) the LCI will accelerate slightly to reach this speed. Just as we noted before, the LCI calculates the actual speed reference based on either the milliamp level of this reference or the counts in SS_REF_OUT and if this reference is slightly low the motor speed may not reach exactly 14.5%. This is important since the next step in the Mark VI is to fire the turbine, and one of the checks the Mark VI does is to see if turbine speed is at least 14.0% before it tries to fire the turbine. If speed does not reach a level high enough at this point to fire the turbine, it is probably because the speed reference level from the Mark VI is slightly low. We calculated in a previous example in Section 1 of this document that the reference from the Mark VI would be at 6.32 milliamps for 14.5% speed or 2900 counts if sent over EGD. Since there is no adjustment capable in the LCI, a problem with this reference can only be solved if the Mark VI fire speed reference is raised slightly so the turbine speed will be above 14.0%. This problem is rare but has occurred a few times.

- As soon as the LCI starts running the motor at firing speed, the turbine attempts to fire. Once the Mark VI sees combustion it starts a 1 minute warm-up time. When the warm-up time is complete signal L2WX becomes a "1" which energizes coil L83SS_FULSPD. This drops out coil L83SS_FIRE and also changes the speed reference to the LCI to 100%. When the LCI sees that the speed reference has been increased to 100% it starts to accelerate the motor towards top speed.
- The LCI increases motor speed at this point by increasing output voltage. Once the output of the LCI reaches its maximum of 4160 VAC, it starts lowering the analog reference to the EX2000 as speed increases in order to maintain constant voltage out of the LCI. This starts a decrease in field current that will continue until the LCI completes the start. The LCI will increase output current as motor speed increases and current will reach a maximum level near 50% speed. The turbine is also working to accelerate the rotor at this time, so the turbine and the LCI are working together to accelerate the unit.
- When motor speed reaches approximately 82% of top speed the LCI starts to decrease its output current and continues to do this until approximately 90% speed. This decreases the work that the LCI is doing and the turbine is capable of increasing the speed of the unit at this point. Once speed has reached 90% and current output has been lowered to a minimum level, the LCI shuts off. The speed points where the LCI starts to decrease output and where it shuts off are set by constants in the LCI control. The analog output reference to the EX2000 is zeroed when the LCI shuts off. Since the LCI is shut off it takes away its "Running" signal to the Mark VI, and signal L4SS_RUN will become a "0" in the Mark VI. The loss of signal L4SS_RUN causes coil L4EX_START to drop out which energizes coil L4EX_STOP in the Mark VI and this stops the EX2000. The loss of signal L4SS_RUN in the Mark VI also starts the LCI "disconnect sequence" by energizing coil L83SS_DISCON. This energizes coil L69SS_DISCON that trips breaker 52SS if the Mark VI is controlling this breaker. If breaker 52SS is operated by the LCI, then 52SS will trip as soon as Runx drops out in the LCI. This causes Genius output SBTRP to energize that energizes SWGRC which will trip breaker 52SS. Since L69SS_DISCON is a "1" it will open disconnect switch 89SS by energizing coil L89SSXO. Once disconnect switch 89SS opens it sends a status contact L89SSO back to the Mark VI indicating that it is open, and this energizes coil L89NDXC which closes disconnect switch 89ND. Once disconnect switch 89SS has fully opened, disconnect switch 89ND has fully closed and LCI breaker 52SS is open the Mark VI energizes coil L3SS which completes the Disconnect Sequence. The Disconnect Sequence includes status of LCI breaker 52SS only if the Mark VI closes breaker 52SS or if the Mark VI tells the LCI to close 52SS.
- The EX2000 was in Static Start Mode, but once disconnect switch 89SS is fully open signal L4EXSS goes to a "0" which takes the EX2000 out of Static Start Mode. Light SSMODE on the OC2000 will go out. When Static Start Mode drops out in the EX2000 it disables the external input from the LCI and

unforces Manual Regulator mode which allows the EX2000 to switch into Automatic Regulator mode.

- Once the generator reaches 95% speed the EX2000 will be restarted automatically by the Mark VI with the Automatic Regulator active. The turbine will continue to increase speed to 100% and the EX2000 will bring generator voltage up to rated voltage.

Section 3 – Other System Considerations

Start with Hydrogen or Air in the Generator?

For the last couple of years there has been a question that arose on almost every jobsite, and that is can a unit be started with air in the generator instead of hydrogen. We have usually resisted starting these units with air in the generator since the Generator Department had stated that it was significantly harder on the generator to start with air instead of hydrogen. Now new data has been taken by the Generator Department regarding this issue, and while they have not issued any new instructions about this situation I feel that their response to the data is such that there will soon be a modification to their instruction book for the generator that allows starts in air. So, I think we can start these units with air in the generator but we should probably restrict the number of starts per hour to less than we normally would with hydrogen in the generator.

Frequency of Starts or Start Attempts

When discussing starting frequency, how many starts in a row or how many starts an hour can be attempted, it should be noted that there is a limitation on starts in this system. The area of concern relates to generator field heating. Attempting too many starts in a row could cause increased heating in the generator field, which while not necessarily an immediate danger could reduce the expected life of the generator if insulation temperatures reach dangerous levels. The 7FH2 generator is designed to allow continuous operation at water wash speeds and above. This means that the generator field would not overheat if the unit ran continuously at purge speed, for example. But trying multiple aborted starts is harder on the generator than continuous operation at purge speed.

Even with hydrogen in the generator there are still some other factors to consider. One situation that increases generator field heating is performing aborted start attempts one right after another. When the generator is being used as a motor the most field current occurs during the initial start. Also, the least amount of cooling occurs at this time since the rotor has hardly any flow of hydrogen around it due to the low speed of the rotor. Another factor that should be considered is the ambient temperature of the rotor. If the unit has been operating as a generator recently and is about to be restarted, the temperature of the rotor will be higher than ambient and has to be considered when determining how many starts will be allowed.

For these reasons we normally do not allow repeated starting attempts to be made without some time between starts. Since these units are to be started from turning gear speed, it is not recommended to try any starts before a unit returns to turning gear speed and to also allow five or ten minutes between start attempts. This will insure that the field temperature will remain within reasonable limits. With air in the generator it would not be unusual to wait 20 to 30 minutes between start attempts.