APPLICATION AND INSTALLATION GUIDE

GAS CONTROL SYSTEMS & IGNITION

G3600 • G3500
G3400 • G3300

CATERPILLAR®

Contents

Foreword

This section of the Application and Installation Guide generally describes Gas Control Systems and Ignition for Caterpillar® engines listed on the cover of this section. Additional engine systems, components and dynamics are addressed in other sections of this Application and Installation Guide.

Engine-specific information and data is available from a variety of sources. Refer to the Introduction section of this guide for additional references.

Systems and components described in this guide may not be available or applicable for every engine.

Gas Control Systems & Ignition

Caterpillar engines have evolved from mechanically controlled workhorses to sophisticated, electronically controlled, intelligent machines. Control systems and ignition on Caterpillar engines have achieved industry leading reliability and durability levels while being subjected to rigorous conditions.

SECTION CONTENTS

Ignition Systems

Ignition System Diagram for G3306 Engine

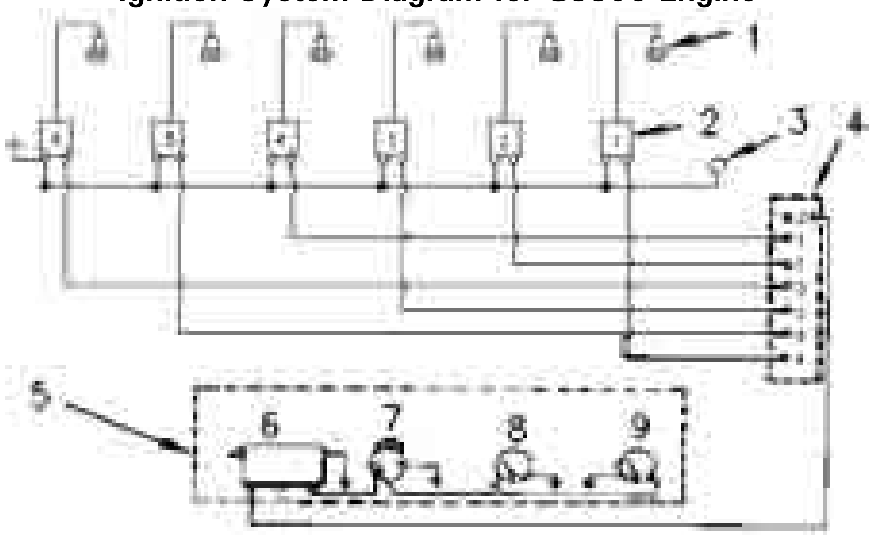

Figure 1

1. Spark Plug
2. Ignition Transformer
3. Ground for Magneto Case
4. Magneto
5. Instrument Panel
6. Magnetic Switch
7. Stop Switch
8. Engine Oil Pressure Gauge
9. Water Temperature Gauge

Caterpillar gas engines use a low voltage ignition system. Individual ignition transformers are mounted near the spark plug for each cylinder. Each engine is equipped with a solid-state magneto, a Caterpillar Digital Ignition System (CDIS), an Electronic Ignition System (EIS), or an Electronic Control Module (ECM). These offer a flexible ignition system that require less maintenance and provide more reliability than older breaker-point magnetos.

Solid-State Magneto System

Figure 1 is a diagram showing the major components of the Solid-State Magneto Ignition System, currently used on G3300 engines.

The magneto produces low voltage for the ignition transformers on each cylinder. The transformers increase the low voltage to the high voltage needed to fire the spark plugs.

Applications not having a 24 VDC electrical power source, such as gas compressors at remote sights, must find a source of electricity to power auxiliary panels. G3300 engines have a pin available on the magneto that can be used to provide power for auxiliary panels. This pin provides 180 VDC with a maximum current draw of 20mA; however, spark plug life will be decreased when the magneto is used to power auxiliary panels.

Caterpillar Digital Ignition System (CDIS)

Figure 2 is a diagram showing the major components of the Caterpillar Digital Ignition System (CDIS) currently used on some G3400 engines.

The CDIS uses a capacitor to store the voltage required for ignition. The timing control has a relay switch that releases the low voltage to the ignition transformers, which increase it to the high voltage that is needed to fire the spark plugs.

There are two options for providing the electrical power for the timing control:

- An engine mounted alternator enables self-powered ignition.
- Customer provided 12VDC or 24 VDC power source.

Caterpillar Digital Ignition System (CDIS) Diagram for G3400 Engine

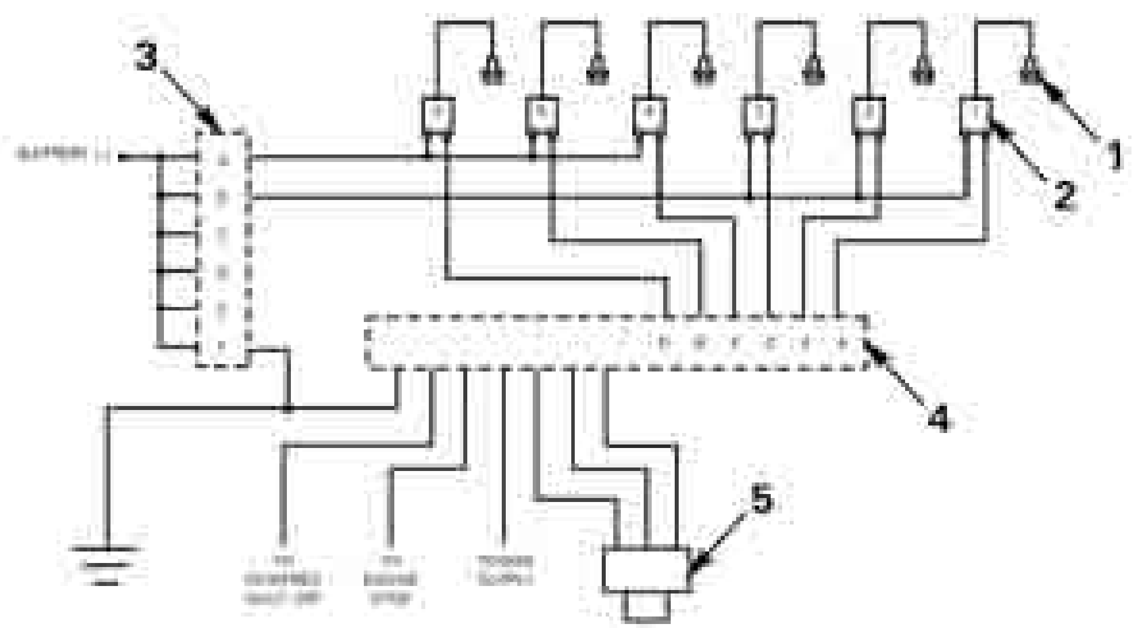

Figure 2

1. Spark Plug
2. Ignition Transformer
3. Ground for CDIS Module
4. CDIS Module
5. Speed Timing Sensor

Electronic Ignition System (EIS)

Caterpillar Electronic Ignition System (EIS)

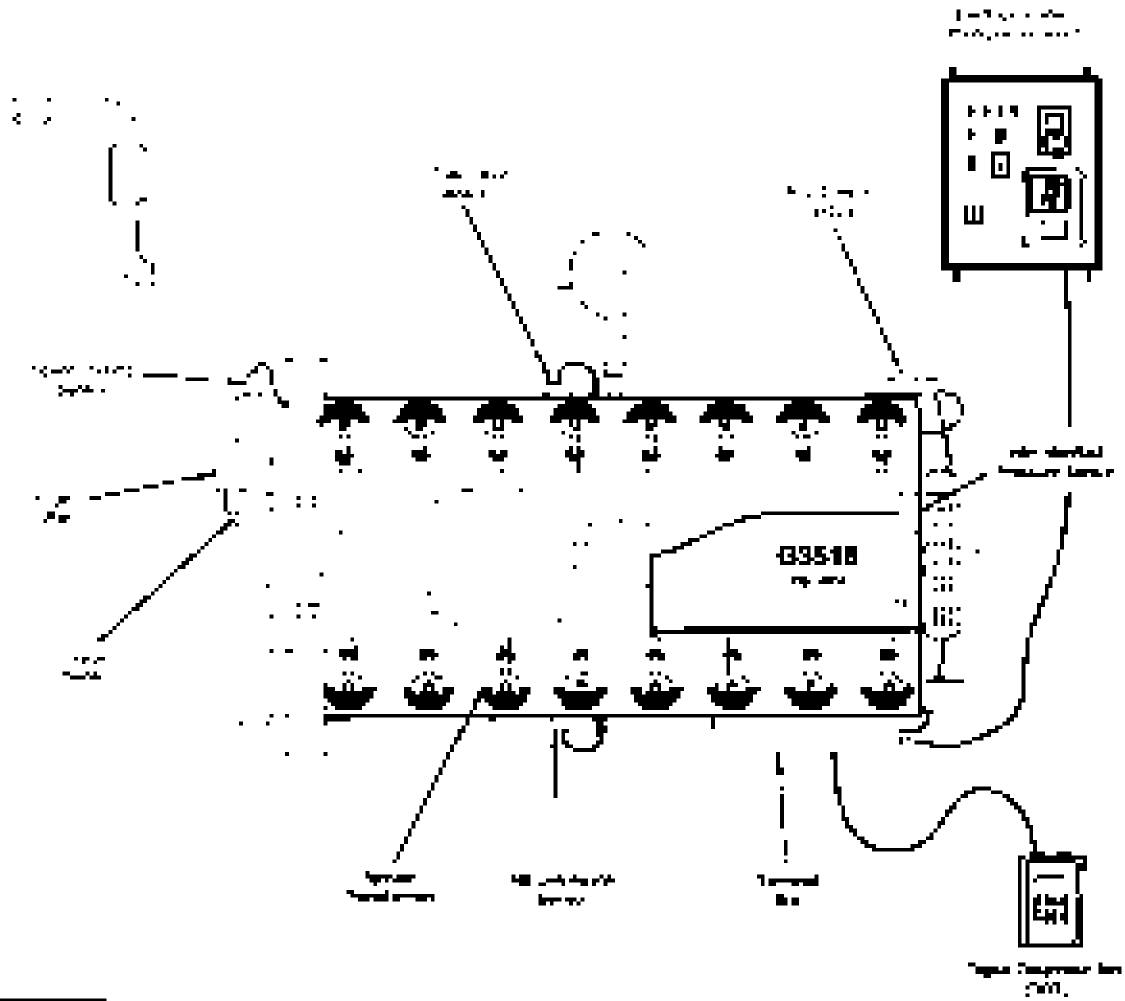

Figure 3

Figure 3 is a diagram showing the major components of the Caterpillar Electronic Ignition System (EIS) currently available on G3400 and G3500 engines. The EIS system monitors engine operation and distributes power to the cylinder transformers to provide the best engine performance at all engine speeds. EIS provides detonation protection and precision spark control for each cylinder.

Gas engines with EIS incorporate a control system that senses and reacts to a combustion detonation by controlling ignition timing. An accelerometer and electronic buffer unit is mounted on each side of the cylinder block, and is used to sense the detonation level (if any). When a level of detonation is reached that might damage the engine, the electronic timing control retards the ignition timing six degrees. If the engine continues to detonate, the control will provide a signal to shut the engine down. If the retarded timing successfully stops the detonation, the timing control will begin advancing the timing at a rate of 1 degree per minute up to the original timing. The timing control will stop advancing if detonation begins again. This allows the engine to obtain optimum fuel consumption by running close to detonation without damaging the engine.

The EIS control module sets engine timing according to desired engine timing, customer specified parameters, and the conditions in which the engine operates. Timing is automatically adjusted according to speed/timing maps, manifold air pressure, and any detonation. The control module also creates diagnostic codes if a problem develops in a component or harness.

Engine sensors provide information to the EIS control module. Detonation sensors are located on each side of the engine and continually monitor the engine for combustion detonation. A speed/timing sensor provides accurate spark timing and engine speed information. An intake manifold air pressure sensor provides engine load information.

The timing is set by connecting the Caterpillar Digital Diagnostic Tool (DDT) or Caterpillar Electronic Service Tool (Cat ET) to the engine to electronically set the timing. The DDT and Cat ET, which are available through the price list, are also used to monitor engine speed, detonation level (if any), and diagnostic codes.

For all engines with Caterpillar EIS, a 24 VDC power source is necessary. The power source provided for the engine's control system can also be used to operate auxiliary panels.

Electronic Control Module (ECM)

The ignition system utilized on engines equipped with the Caterpillar ADEM A3 control system is controlled by the system's Electronic Control Module (ECM) described later in this section.

Spark Plugs

Spark plugs for Caterpillar gas engines have been specifically developed to meet the ignition needs of a given engine. The spark plugs must be maintained according to the specified maintenance schedule. Failure to use proper spark plugs, or failure to properly maintain the spark plugs, will affect the engine's fuel consumption, emissions, and stability. Good maintenance practices can be found in Systems Operation Testing and Adjusting Manual for your engine.

Variable Timing for Dual Fuel

The recommended ignition timing varies with fuel composition. Serious engine damage could result if the timing is not changed when the fuel is changed; for example, from natural gas to propane or digester to natural gas. To allow automatic timing adjustment when the fuel is changed, EIS offers a dual timing switch. On the G3300 only, a dual timing magneto is available as well.

The customer must provide the contacts to signal EIS or the magneto to select timing. See the "Fuel Systems" section of this guide for additional information.

In Hazardous Locations

Engines installed in hazardous locations generally fall under the Class I, Division 2 category of Article 500 of the National Electrical Code. It reads:

"A Class I, Division 2 location is a location:

- in which volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of the ventilation equipment; or
- in which ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilation equipment; or
- that is adjacent to a Class I, Division 1 location, and to which ignitable concentrations of gases or vapors might occasionally be communicated unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided."

The basic difference between Division 1 and Division 2 is:

- Division 1 – flammable gases are always present.
- Division 2 – flammable gases may be present.

When an engine is installed in such a location, shielding of the ignition system wiring or usage of approved ignition system components may be required. Many Caterpillar gas engines have attachments providing an ignition system that is Canadian Standards Association (CSA) approved for Class I, Division 2, Group D locations. CSA approval is a Canadian requirement for engines operating in hazardous locations in Canada. CSA approval is also recognized in Division 2 locations outside Canada. Consult factory for availability.

The basis for the CSA attachment design is to prevent hazardous atmosphere from coming in contact with arcing or sparking devices or to contain an explosion within the engine itself. This is accomplished on Caterpillar gas engines by special metal conduit harness assemblies for the ignition system and engine wiring harnesses. Special explosion-proof transformers and cylinder head components have been developed to contain any potential explosion in the head.

The Caterpillar EIS system is available in a CSA approved configuration. This system varies from the standard EIS system by offering special ignition coils and a terminal box located on top of the EIS control module.

With the CSA system, no shutoffs, monitoring systems, start/stop logic or gas shutoff valves are provided. The functions must be provided by the customer. The required shutoffs for jacket water temperature, oil pressure, and overspeed can be found in the Operation and Maintenance Manual for each engine.

The CSA terminal box contains warning, shutdown, and power lamps and a diagnostic reset switch. All of these may be remote mounted by the customer.

For magneto systems with the CSA attachment, troubleshooting can be more difficult. A standard transformer can be installed temporarily so that the timing light can be triggered from the exposed high-tension lead. Detecting a misfiring cylinder is more of a problem with a shielded system. Installation of normally closed switches in the primary wiring is one method of temporarily interrupting ignition to identify a misfiring cylinder. If devices are incorporated in the shielded system for troubleshooting purposes, the primary of the magneto must never be grounded to interrupt the ignition. This would most likely cause failure of solid-state components within the magneto.

Engine Shutdown Practice

Normal engine shutdown should be accomplished by shutting off the fuel supply. This allows the engine to consume the fuel trapped between the shutoff valve and cylinder. It also prevents raw fuel from being pumped into the exhaust system. Raw fuel in a hot exhaust system presents the potential for explosion. Stopping the ignition system to cause engine shutdown should be utilized only for emergencies.

Engine Control, Protection and Monitoring Systems

Control, protection and monitoring systems are a basic requirement of all engine installations, and provide protection to the engine as well as to the facility and operating personnel.

Many gas engines are controlled using separate engine speed governing systems, which are described in the Governors section of the Application and Installation Guide. This section of the guide provides basic information about the Caterpillar ADEM A3 control system and the protection systems available on Caterpillar non-ADEM gas engines. ADEM A3 is standard on G3600 engines and available on some G3500 engines.

Engine protection is required for the lubrication, cooling, and combustion systems. These systems in turn interact with fuel and ignition systems and in some cases, with the customer's switchgear.

The lubrication system must maintain the oil pressure within a certain range; oil temperature is internally controlled via a thermostat for most arrangements. The cooling system must maintain the cooling water below a certain temperature. Some engines have a protection system for the combustion chamber; detonation sensing that can adjust or even shutdown the engine. Overspeed protection is also very important. A listing of standard and optional protection systems can be found with each engine pricing arrangement in the price list. The details of these offerings will be discussed in following sections.

When problems occur that do not immediately endanger the condition of the engine or the operator, the fuel gas valve is closed as soon as a fault is detected and the ignition system remains on for 10 seconds. This allows all the gas downstream of the shutoff valve and in the intake manifold to be consumed by the engine and not dumped into the exhaust stack. When a problem occurs that can cause immediate damage to the engine or operator, such as overspeed, the gas valve is closed and the ignition system is immediately shut off. When starting again, the engine should be cranked for 10 seconds with the gas valve closed and the ignition system off. This purges the engine of any unburned air/fuel mixture.

When designing an installation, consider if the engines will be attended or unattended when selecting protection equipment. When attended, alarms can be provided to warn of approaching shutdown limits in each monitored system before an actual engine shutdown occurs. This allows the attendant to decide the urgency of the fault and schedule repairs before a shutdown. Protection equipment for unattended applications can be tailored to meet specific requirements.

Although most Caterpillar gas engines are equipped with a standard set of shutoffs, some engine configurations include additional shutoffs and alarms. They may also use different strategies for shutdowns, annunciation and other features. Consult the Gas Engine Schematics listed in the Reference Materials at the end of this section for additional information on how to connect to a specific engine's safety system.

Gas generator set engines are normally equipped with Energize-To-Run (ETR) gas shutoff valves. The diesel offers both ETR and Energize-To-Shutoff (ETS). The gas engine differs because there is not a commercially available gas shutoff valve that is energize-to-shutoff with an automatic reset. For manual start-stop operations, ETS gas valves are available as an option for G3400 and G3300 with a manual reset.

G3300 and G3400 Engine Protection Systems

The G3300 and G3400 engines offer several protection system options. In the price list, the desired protection system is selected from a list of mandatory options. Not all options are available for every engine; consult the use codes for compatibility. Descriptions of some available options are listed below.

Self-Powered Shutoffs

These shutoffs are powered by the ignition system when the engine is running; no external power is required. An energized to shutoff gas valve (manual reset) is activated to stop the engine.

Powered Shutoffs

This fully independent system requires an external power supply of 24 volts. The power to an ETR gas valve (optional) is interrupted to stop the engine.

Automatic Start/Stop Shutoff

This system is made for customers that have switchgear that is wired to the junction box in order to monitor shutoff parameters and control an ETR gas shutoff valve. This system requires an external power supply of 24 volts. The customer is required to supply automatic start/stop logic.

Customer Supplied Shutoff

This selection provides no wiring groups or shutoffs. It is the customer's responsibility to provide the minimum protection required for the particular engine and application.

Electronic Modular Control Panel (EMCP) II

This protection system is available for Caterpillar EIS engines and requires an external 24 volt power supply. **Figure 4** shows a typical EMCP II instrument panel. The engine features provided are:

- Emergency stop button
- Energized to run gas shutoff valve
- Power, warning, and shutdown lights
- Detonation
- Start, stop, run switch

The EMCP II Protection System also contains a generator set control (GSC) and several instrument panel switches plus optional alarm modules and customer interface module. The GSC monitors and controls:

- Starting and stopping of the engine
- Shows engine condition and generator output display
- Engine faults, displays fault codes
- Displays GSC programming information

The safeties and controls listed above are all contained in the EMCP II. The set points for the various shutoff parameters are programmed into the EMCP II using a keypad on the GSC.

G3400 EMCP II Instrument Panel

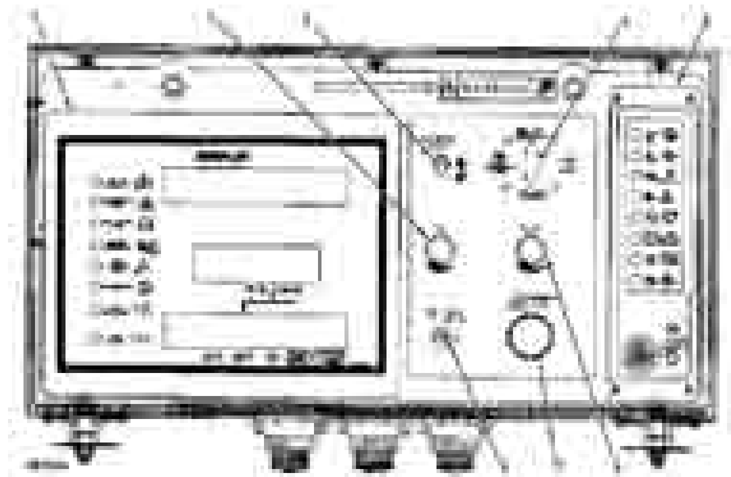

Figure 4

1. Generator Set Control (GSC)
10. Speed Potentiometer or Governor Switch (Optional)
11. Diagnostic Reset Switch
12. Engine Control Switch
13. Alarm Module or Synchronizing Lights Module (Optional)
14. Panel Light Switch (Optional)
15. Emergency Stop Push Button
16. Voltage Adjust Rheostat

G3500 Engine Protection System

G3500 engines offer an electronic protection system that requires a 24 volt power source. The gas shutoff valve is included and configured as ETR. The control panel for protection system hardware will be one of four offerings:

- Remote Control Panel (Status), offered on all G3500 EIS generator set and industrial engines except G3500 package generator sets for COSA. A description of the Status Control panel is located below.
- Electronic Modular Control Panel (EMCP II), mounted on the generator, standard for the 1800 rpm generator set standby package, optional for G3500 package generator sets for COSA, and available via SER for other generator set engines.
- Caterpillar Advanced Digital Engine Management (ADEM) A3 control system is available on some G3500 engines.
- Customer supplied control panel, safeties, shutdowns, and start/stop logic, standard on G3500 Package Generator sets for COSA.

Remote Control Panel

The remote control panel (Status) is used on most engines with Caterpillar EIS. **Figure 5** shows the remote control panel (Status) and labels the various panel features.

Remote Control Panel (Status)

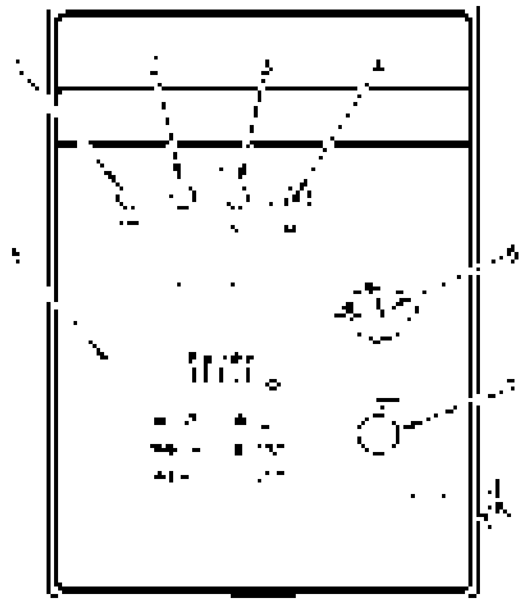

Figure 5

1. "Warning" indicator
17. "Shutdown" indicator
18. "Power On" indicator
19. "Diagnostic Reset" switch
20. Status Control Module (SCM)
21. Engine Control Switch (ECS)
22. "Emergency Stop" button

The Status Control Module (SCM), shown in **Figure 6**, displays fault conditions and key engine parameters. Information is received from the operator, magnetic speed pickup, pressure/temperature module, and the EIS control. This information is then used to control the position of the fuel shutoff valve, starting system, and relay information back to the ignition system.

Status Control Module (SCM)

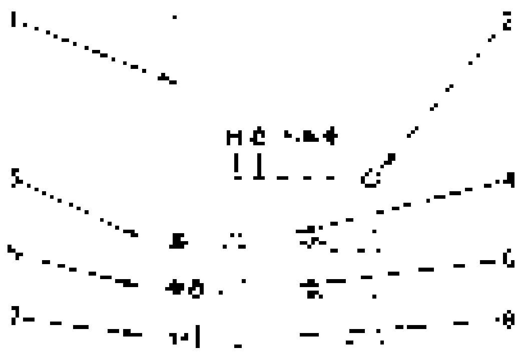

Figure 6

1. (Liquid Crystal Display (LCD)
23. Switch (display hold switch)
24. "Overcrank" indicator
25. "Low oil pressure" indicator
26. "Overspeed" indicator
27. "Emergency Stop" indicator
28. "High Coolant Temperature" indicator
29. "Auxiliary shutdown" indicator

Electronic Modular Control Panel (EMCP) II+

A second protection system, available on G3500 generator set engines, is the EMCP II+. The EMCP II+ also contains a generator set control (GSC) and several instrument panel switches plus optional alarm modules and a customer interface module. An EMCP II+ instrument panel is shown in **Figure 7**.

The GSC monitors and controls the following items.

- Starting and stopping of the engine (This is not applicable for ADEM A3 controlled G3500 engines)
- Shows engine condition and generator output display
- Engine faults, displays fault codes
- Displays GSC programming information

The safeties and shutdowns listed above are all contained in the EMCP II+. The set points are programmed into the EMCP II+ using a keypad on the GSC.

G3500 EMCP II+ Instrument Panel

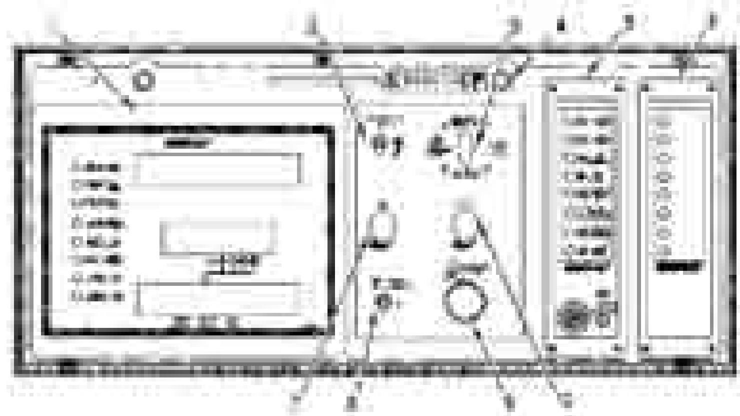

Figure 7

1. Generator Set Control+ (GSC+)
2. Engine Control Switch (ECS)
3. Start Aid Switch (SAS)
4. Panel Lights (PL)
5. Alarm Module (ALM) (Optional)
6. Synchronizing Lights Module (Optional) or Custom Alarm Module (CAM) (Optional)
7. Speed Potentiometer (SP) (Optional) or Governor Switch (Optional)
8. Voltage Adjust Rheostat (VAR)
9. Emergency Stop Push Button (ESPB)
10. Panel Light Switch (PLS)

Alarm Modules

Alarm modules are optional equipment, available as an attachment to the EMCP II+. These modules provide red and amber LED's plus an audible indicator.

Two alarm modules are available. They are the NFPA 99 and NFPA 110. The NFPA 99 provides alarms for low oil pressure, low coolant temperature and high coolant temperature. The NFPA 110 provides alarms for low oil pressure, low coolant temperature and high coolant temperature, low battery voltage, battery charge malfunction and system not in auto.

The alarm module has a serial connection to the SCM and must be located within 305 m (1000 feet).

When using alarm modules and panels not produced or offered by Caterpillar, be sure that the module(s) includes the following features.

- Fault Light Lock-in Circuitry - keeps fault light on when intermittent faults occur.
- Lockout of Additional Alarm Lights - prevents subsequent alarm lights from going on after the activated engine shutoff stops the engine. This aids in troubleshooting.
- Alarm Silence - allows engine man to acknowledge the alarm without having to continually listen to the alarm horn. Alarm light is left on.
- If more than one engine is connected to an alarm panel, a fault in a second engine should activate the alarm, even though the alarm horn

may have been silenced after a fault on another engine.

- Circuit Test - provides for periodic checking of alarm panel functions

Customer Interface Module (CIM)

The Customer Interface Module (CIM) provides an interface (separate relay contacts) between the GSC and switchgear on EMCP II+ equipped engines and between the SCM and switchgear on RCP equipped engines.

The two major components of the CIM are the relay board and the electronic control. The electronic control connects to the serial data link and decodes the information into discrete outputs. The output drives relays to sound a horn, flash a lamp or trigger some other action. The following information is available from the serial data link.

- High coolant temperature alarm
- High coolant temperature shutdown
- Low coolant temperature alarm
- Low coolant temperature shutdown
- Low oil pressure alarm
- Low oil pressure shutdown
- Overcrank
- Overspeed
- Engine control switch not in auto
- Diagnostic failure

The CIM is normally shipped loose for installation in a convent location, such as the switchgear. The CIM must be located within 305 m (1000 ft) of the GSC or SCM.

Customer Communication Module (CCM)

The Customer Communication Module (CCM) provides a communication link between the electronic control system of an engine and a host device. A typical CCM is shown in **Figure 8**. The communication link is established with the CAT Data Link and the industry standard RS-232C. The host device can be one of the following items:

- Personal Computer (PC)
- Programmable Logic Controller (PLC)
- Any other device with an RS-232C port

The host device can be connected directly to the CCM and can be used with a modem.

If the host device is a PC, software that is compatible with the CCM is available from Caterpillar.

The host device will usually be a PLC and the CCM can be used with customized software. Refer to the Operation and Maintenance Manual for each engine for further information on this subject.

Customer Communication Module

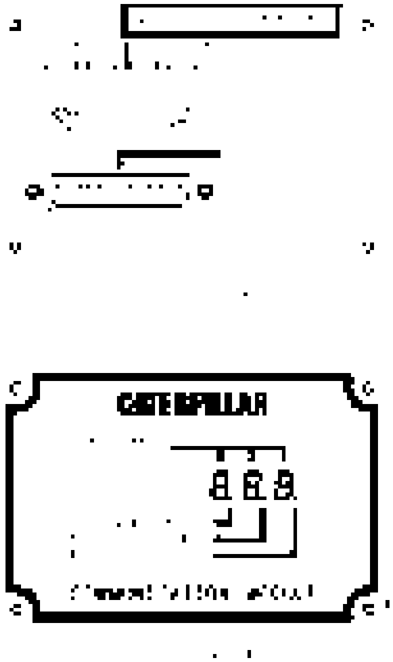

Figure 8

Customer Supplied Shutoffs

Customer supplied shutoffs must meet all Caterpillar and other local requirements. Caterpillar requires at a minimum a duplication of the safeties and shutdowns that would have been provided by Caterpillar for the particular engine. These safeties and their limiting values are shown for each engine in the product description section of the price list and in the Operation and Maintenance Manual for each engine. For a typical standard cooling G3500 LE, the Caterpillar system provides:

- Emergency stop button
- Energized to run gas shutoff valve
- Power, warning, and shutdown lights
- Detonation
- Start, stop, run switch

When the high temperature cooling option is selected, the following are used:

For engines operating above a jacket water temperature of 110°C (230°F), a Caterpillar pump may not be used. When using a customer supplied pump, Caterpillar requires that a shutdown be provided for low jacket water flow. This can be done with a pressure switch or a pressure differential switch across the engine block, triggering below 27 kPa (4 psig) delta.

Recommended Alarms and Shutdowns

The engine shutoff systems discussed above are the standard systems. Customers routinely add alarms and shutdowns to meet the needs of the application. **Table 1** suggests various alarms and shutdowns to be considered and how they might be applied. This chart is frequently modified to fit the site, application, and maintenance personnel preferences.

Gas Engine Controls and Safety Devices		
Malfunction	**Unattended**	**Attended**
Low oil pressure	S	S
High oil pressure	S	A
Excessive vibration	S	S
Overspeed	I	I
High inlet air temperature	S	S
Alarm shutdown	S	S
Detonation	I	I
Overcrank	S	S
High jacket water temperature	S	S
High water level	A	A
Low water level	S	A
Reverse power	S	S
Overcurrent	S	S
High steam pressure	A	A
Overloaded	S	A
Under frequency	S	S
Over/under voltage	S	S
Battery charger failure (AC)	A	A
Battery failure (DC)	A	A
Low condensate level	S	S
Low tower water level	S	A
I – Immediate shutdown – close gas valve and terminate ignition immediately S – Staged shutdown – close gas valve immediately and terminate ignition after 10 second time delay A – Alarm only		

Table 1

Advanced Digital Engine Management (ADEM) A3 Control System

The Caterpillar Advanced Digital Engine Management (ADEM) A3 electronic controls integrate start/stop controls, governing, engine sensing/monitoring, air/fuel ratio control, ignition timing and detonation control into one comprehensive engine control system for optimum performance and reliability.

The ADEM A3 control system is shown in **Figure 9** and includes the following components:

- Electronic Control Module (ECM) and emergency stop button in an engine mounted junction box
- Integrated Temperature Sensing Module (ITSM)
- Gas Shutoff Valve (GSOV)
- Ignition system controlled by ECM
- Detonation sensor for each two cylinders
- Electronically controlled actuators for fuel, throttle and turbocharger bypass

G3500 ADEM A3 Control System

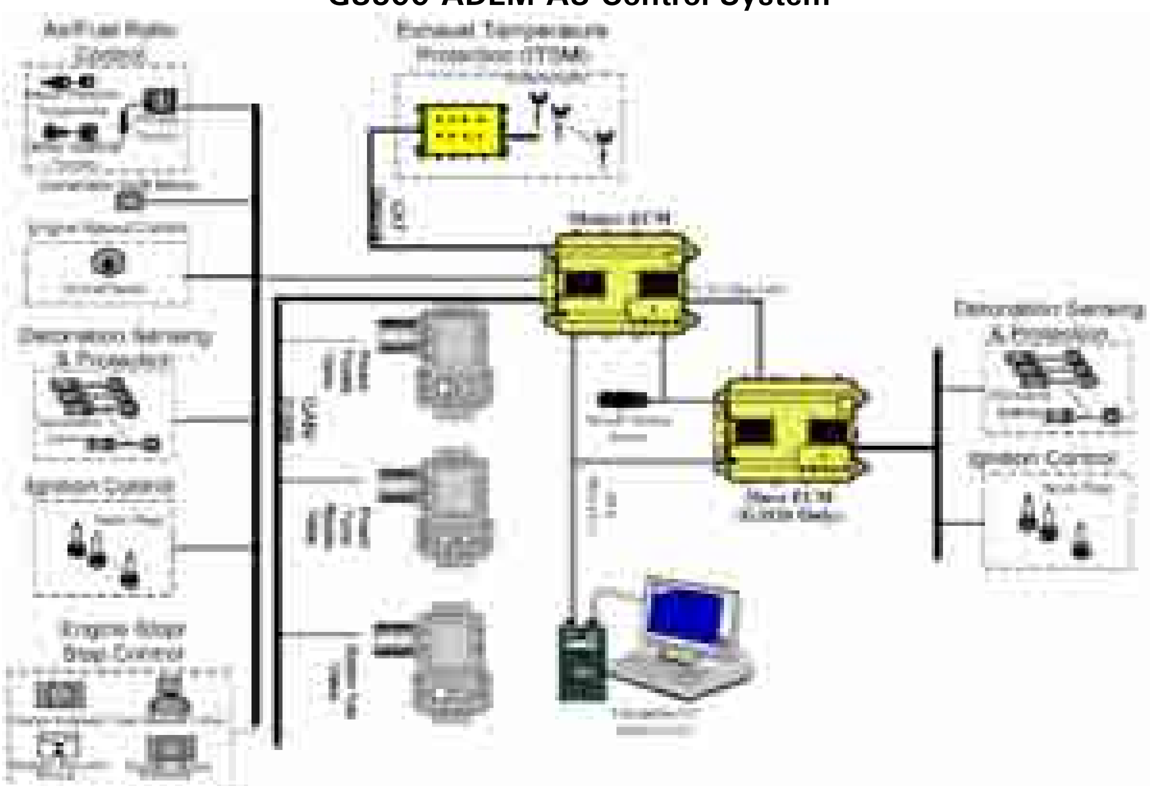

Figure 9

Electronic Control Module (ECM)

The Electronic Control Module (ECM) controls most of the functions of the engine. The module is an environmentally sealed unit that is in an engine-mounted junction box.

The ECM monitors various inputs from sensors in order to activate relays, solenoids, etc. at the appropriate levels. The ECM supports the following five primary functions:

- Governing of the engine
- Control of ignition
- Air/fuel ratio control
- Start/stop control
- Engine monitoring and protection

The ECM control parameters are all preset at the factory with any site specific reprogramming done by Caterpillar service personnel during the commissioning process utilizing Cat ET service tool. The following is a brief description of these five functions:

Governing of the Engine

The ECM monitors the actual engine speed, and calculates the difference between this and the desired engine speed. The ECM then adjusts the air/fuel flow by controlling the throttle to maintain the desired engine speed.

Control of Ignition

Each cylinder has an ignition transformer. To initiate combustion, the ECM sends a pulse of approximately 108 volts to the primary coil of each ignition transformer at the appropriate time and for the appropriate duration. The transformer increases the voltage, which creates a spark across the spark plug electrode.

The ECM provides variable ignition timing that is sensitive to detonation. The detonation sensors (one for each two adjacent cylinders) monitor the engine for excessive detonation and provide this data to the ECM. If detonation reaches an unacceptable level, the ECM will retard the ignition timing of the affected cylinder or cylinders. If retarding the timing does not limit the detonation to an acceptable level, the ECM will shut down the engine.

A normal engine shutdown is accomplished by shutting off the fuel supply. The ignition system continues to operate until the engine is below 60 rpm. This allows the engine to consume the fuel that is trapped between the shutoff valve and the cylinder. The ignition system is disabled for engine overspeed and emergency stop shutdowns.

The ECM provides extensive diagnostics for the ignition system. The ECM also provides a switch for ignition timing in order to allow operation with alternate fuels that require a timing offset.

Levels of detonation can be displayed by the MIDS on the Optional Control Panel. Alternatively, the "Cylinder X Detonation Level" screen on the Cat ET service tool can also be used. The "X" represents the cylinder number.

Air/Fuel Ratio Control

The ECM provides control of the air/fuel mixture for performance and for efficiency at low emission levels utilizing the fuel valve and oxygen sensor. The system has three modes of operation for the air/fuel ratio:

- Start-up
- No feedback
- Exhaust oxygen feedback or Charge density feedback

Note: The engine uses either exhaust oxygen or charge density.

In each of these modes, the air/fuel ratio is controlled by the fuel valve.

Exhaust Oxygen Feedback

Because most, if not all, of the oxygen in the combustion chamber comes from the air in the inlet charge, exhaust oxygen levels are a direct result of the air/fuel ratio being provided. An oxygen sensor in the exhaust stack measures the oxygen level in the exhaust. This information is provided as feedback to the AFRC, which compares the measured oxygen level to that of the correct air/fuel ratio for the desired emissions setting.

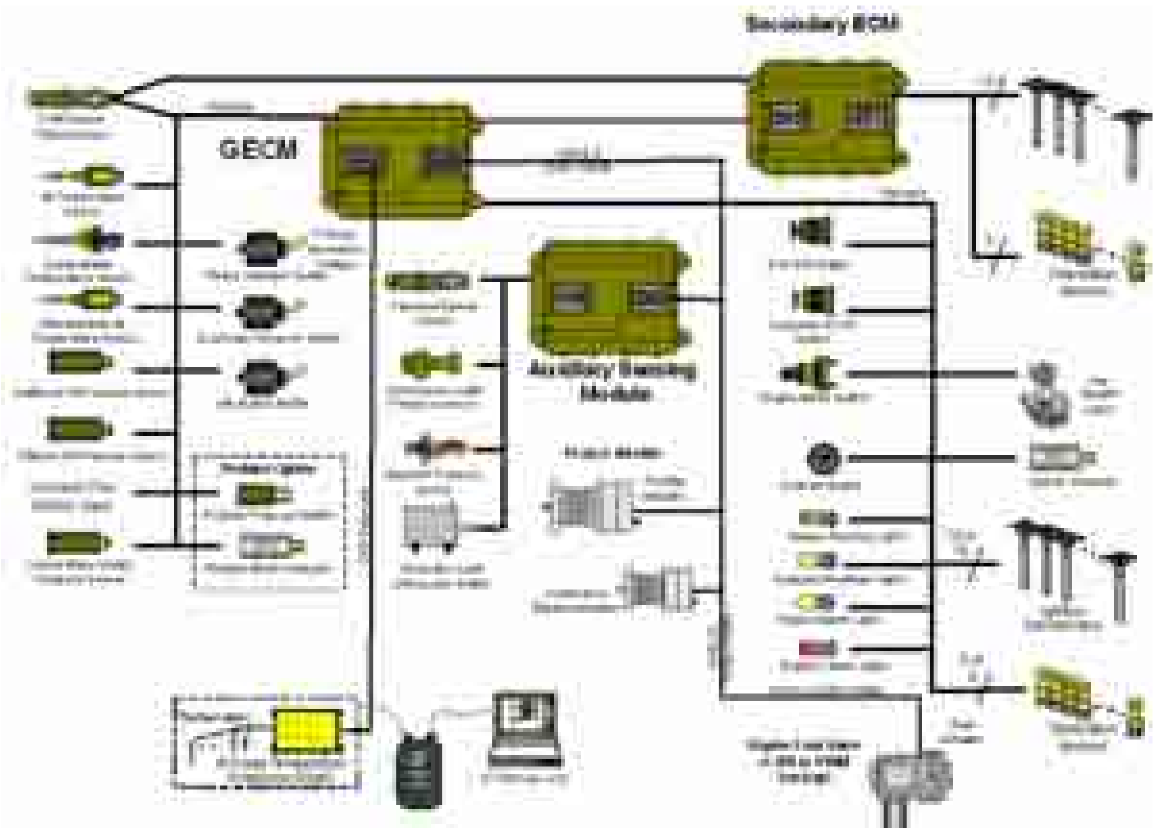

Figure 10

Charge Density Feedback

Charge density is the density of the air/fuel mixture in the air inlet manifold. The ECM calculates the actual charge density from the values of inlet manifold air temperature and air inlet pressure and compares it to the desired charge density. Desired charge density is dependant on engine speed and real engine load.

For standard G3500C and E packages the real engine load is calculated and sent to the ECM by the EMCPII+. However, for G3500C and E packages with the Island Mode control system (Coal Mine Methane, Island Mode and 50Hz Landfill) the ECM requires a continuous and instantaneous measurement of the real engine load to adequately adjust for load and fuel transients. For this reason Caterpillar provides a kilowatt transducer, which supplies the ECM with a 0.2-4.8V DC analog signal proportional to the measured real power.

To achieve the desired charge density, the ECM sends a command signal to the fuel metering valve. This is a continuous process during operation with loads that are greater than 25 percent. The same customer's inputs that are required for operation in the open loop are used for the feedback mode. The following additional configuration parameter must be programmed into the ECM via the "Configuration" screen of Cat ET:

"Desired Emissions Gain Adjustment Percentage" - This is an adjustment for the charge density. To richen the air/fuel mixture, increase the gain adjustment. To lean the air/fuel mixture, decrease the gain adjustment. This increases the charge density and lowers NO_x. The ECM uses the gain adjustment to help determine the FCF. The FCF varies during operation in the feedback mode.

Note: A small change in the "Desired Emissions Gain Adjustment Percentage" causes a large change in the actual exhaust emissions. For example, an adjustment of one percent in the parameter's value will result in a change of 20 to 40 ppm in the actual level of NO_x.

G3500C & E Island Mode Control System

Island mode applications are defined as stand-alone applications without any connection to the utility grid, parallel with other units not connected to the utility grid, connected to a small utility grid which can experience frequency and voltage changes, or paralleled to grid, but when grid is "down", the genset must operate stand-alone with minimum freq/voltage variation. The island mode control system provides additional sensors, controls and software to permit improved transient operation. Check the appropriate product update (LEXE7567) on the PowerNet for detailed transient information.

Caution: Gas engine gensets cannot accept transient conditions equal to a diesel genset or a large utility grid. It is the dealer's responsibility to be sure the customers' needs are matched to this product's capability.

Kilowatt Transducer – Island Mode Control System

The Island Mode control system utilizes a kilowatt (kW) transducer to provide a real time, real power signal to the engine control system (Figure 10). The kilowatt transducer measures the electrical power delivered to a load and converts that measurement to a DC Voltage proportional to the power measured. The kW transducer monitors both the voltage and current using potential transformers (PT's) and current transformers (CT's) and calculates the power based on the circuits PT and CT outputs. The PT and CT ratios directly impact the output voltage of the kW transducer and need to be sized to maximize the kW transducer output voltage. At a minimum the kW transducer full-scale output voltage needs to be 4.0V, however it should not exceed 4.8V. If the voltage at the load input on the ECM ever exceeds 4.8 volts then the ECM will trigger a "Kilowatt Sensor Open or Shorted high" diagnostic and the engine will shutdown. If the voltage is ever less than 0.2 volts and the engine is above 20% load (based on traditional load calculation) then the ECM will trigger a "Kilowatt Sensor Shorted Low Diagnostic."

Selecting a transducer

For accurate power measurement, kW transducers must measure the power in each branch of the circuit, which depending on the load requires either a two or three element kW transducer. The kW transducer provides the following measuring function:

Power (Two Element, Three-Phase, Three-Wire) = V_{L-N} x I x 1.732 x pf

Power (Three Element, Three-Phase, Four-Wire) = V_{L-L} x I x 3 x pf

Applications with three-phase, four-wire power, which utilize line-to-line and line-to-neutral loads that could produce unbalanced loading, require a three-element kW transducer to accurately monitor the power. Applications utilizing three-phase three-wire balanced connection only require a two-element transducer to accurately measure the power.

Kilowatt Transducer Output Voltage

PT and CT ratios should be selected to maximize the kilowatt transducer output voltage at genset full load. A full scale output less than 4.0V DC will degrade the transient capability of the engine due to the increased kW/V range and increased susceptibility of noise. The following calculations are used to determine the kilowatt transducer output at the full load of the Genset based on PT and CT ratios.

Caution: The kW transducer should be selected such that the maximum is 110% of the generator's rated output. For example, if the generator has a rated output of 1700 ekW, the maximum output is 1870 ekW. When the generator's output is 1870 ekW, the kW transducer will provide a signal of approximately 4.8 VDC. In addition, the kW transducer output voltage at 100% of the generator's rated output needs to be no less than 4.0V. For many packages a kW transducer with an output voltage range of 0-10VDC is used to meets the 4.0V minimum output voltage required by the ECM. PT's and CT's should be sized so the output voltage does not exceed 4.8V at 110% of the generator's rated output even though the kW transducer has a 10V range.

KW Transducer output Voltage at 100% Rated Genset output:

$$\frac{PT(ratio)\times CT(ratio)\times(transducer\ \ full\,scale\,Watts)}{Genset\ Rated\ Output\ Power}=Ratio\ of\ \ Tranducer\ \ Output\,'$$

$$\frac{(Transducer\ Full\ \ Output\ \ Voltage)}{Ratio\ of\ \ Transducer\ \ Output}=Transducer\ \ Output\ \ Voltage\,@\ Full\ \ Rated\ \ Genset\ \ Power$$

Example:

PT ratio = 14,400:120   CT ratio = 200:5

$$\frac{120(PT\ \ ratio)\times 40\,(CT\ \ ratio)\times 1000(transducer\ \ full\,scale\,Watts)}{2055000\ (Genset\ Rated\ Output\ Power\ \ in\ Watts)}=2.336\ (Ratio\ of\ \ Tranducer\ \ Output)$$

$$\frac{10V\ (Transducer\ Full\ \ Output\ \ Voltage)}{2.336\ (Ratio\ of\ \ Transducer\ \ Output)}=\ 4.281\ (Transducer\ \ Output\ \ @\ \ Full\ \ Rated\ \ Genset\ \ Power)$$

KW Transducer output Voltage at 110% Rated Genset output:

$$\frac{PT(ratio)\times CT(ratio)\times(transducer\ \ full\,scale\,Watts)}{Genset\ Rated\ Output\ Power\ *1.10}=Ratio\ of\ \ Tranducer\ \ Output$$

$$\frac{(Transducer\ Full\ \ Output\ \ Voltage)}{Ratio\ of\ \ Transducer\ \ Output}=Transducer\ \ Output\ \ Voltage\,@\ Full\ \ Rated\ \ Genset\ \ Power$$

Example:

PT ratio = 14,400:120   CT ratio = 200:5

$$\frac{120(PT\ \ ratio)\times 40\,(CT\ \ ratio)\times 1000(transducer\ \ full\,scale\,Watts)}{2055000\ (Genset\ Rated\ Output\ Power\ \ in\ Watts)*1.10}=2.123\ (Ratio\ of\ \ Tranducer\ \ Output)$$

$$\frac{10V\ (Transducer\ Full\ \ Output\ \ Voltage)}{2.123\ (Ratio\ of\ \ Transducer\ \ Output)}=\ 4.709\ (Transducer\ \ Output\ \ @\ \ Full\ \ Rated\ \ Genset\ \ Power)$$

Selecting Potential Transformers (PT's)

PT's are precision transformers that step the voltage down to a voltage range that is suitable to the kW transducer input. The kW transducers are self-powered and have a specific input voltage range that needs to be met to guarantee performance. PT's should be selected so that the secondary voltage does not drop below the minimum input requirement of the kW transducer during load transients. A two-element watt transducer monitoring a three-phase, three-wire load are rated for line-to-line voltage and a three-element watt transducer monitoring a three-phase, four-wire load is rated for line-to-neutral voltage. Any load connected to the PT including the kW transducer have an associated burden on the PT, therefore care should be taken not to exceed the transformer burden rating.

Selecting and Sizing Current Transformers (CT's)

The kW transducers supplied by Caterpillar have a current input range of 0-5A, and therefore CT's should be selected so that the maximum secondary current of the CT does not exceed 5A. Connect the loads on current transformers in series being careful not to exceed the burden rating. The total burden is the sum of the transducer, interconnecting leads (calculated by using the below formula. Use conductor resistance (total to the device and back), and internal burden of CT windings (usually so small that it can generally be ignored). A CT is most accurate at rated current with a low burden (load). Accuracy decreases with increased burden (load) or low line current. In sizing CT's the conductor size and distance is important. Improper sizing of current transformers or long secondary conductor runs with undersized cable can result in poor accuracy.

The burden can be expressed in volt-amperes:

$VA = I^2 \times Z$

Z = Total CT secondary impedance

I = 5A

Sizing CT's Example:

If the peak load is 500 kW, the peak current on a 480V three-phase system would be:

500,000 / (480 x 1.73 x 0.9 pf) = 669 amps

This assumes a 0.9 power factor. (Peak current would be higher with a lower power factor.) Since the CT should be about 10% to 20% larger than the calculated current and 800:5 CT would be a good selection.

Caution: Current transformers can and will develop a lethal voltage and possibly self-destruct if the secondary is open when the primary current is present. Never disconnect the secondary or leave it open when there is the possibility of primary current.

Watt Transducer Location and Wiring Guidelines

The kW transducer should be mounted near the CT's and PT's for accurate power measurement. In addition it is strongly recommended that the output signal of the kW transducer be a Shielded Twisted Pair Cable of 22 Gauge or larger wire to connect the transducer output to the engine. The shield of the transducer output cable should be grounded at the receiving end only (ECM). In addition it is recommended that the shielded twisted pair output cable be kept as short as possible and should not exceed 100ft due to the susceptibility of noise onto the system. For applications in noisy environments the following things can be done to help improve signal quality.

- Connect a 0.01mfd, 200 volt capacitor between the negative terminal and case
- Ground the case

CDVR Initial Settings (G3520C)

The Caterpillar Digital Voltage Regulator (CDVR) is a microprocessor based voltage regulator. The main purpose of a digital voltage regulator is to regulate the output voltage of a generator that is used with an engine generator set. The following section lists the parameter default settings that have been found to be stable in most cases, however they are far from optimal and should be used as a base line and to just get the system functioning.

CDVR Parameter Settings

- System Configuration
  - Rated Voltage (90 – 15,000V) **120V default**
  - Rated Current (1 – 9,999A) **600A default**
  - Frequency (Sensing 50 or 60Hz) **60Hz default**
  - PT Primary (90 – 15,000V) **120V default**
  - PT Secondary (90 – 600V) **120V default**
  - CT Primary (1 – 9,999A) **600A default**
  - Power Input Freq (50 – 400Hz) **60Hz default**
  - Sensing Mode (1F or 3 F) **3 F default**
- Settings
  - Setpoint
    - AVR Voltage (limited by Volt Adj Band) **120V default**
    - VAR (% of rated, +/- 100%) **0% default**
    - Power Factor (+/- 0.6) **1.0 default**
    - AVR Voltage Control (CAN / Switch) **CAN default**
    - VAR/PF Control (CAN / Switch) **Switch default**
    - Load Compensation Mode (Off, Droop, LDC) **Off default**
    - Load Comp Setpoint (0 to +/-10%) **0% default**
    - Voltage Adjustment Band (0 to +/- 15%) **15% default**
- Settings
  - Startup
    - Soft Start Mode
      - Soft Start Bias (0 – 90%) **10% default**
      - Soft Start Time (0 – 120s) **5s default**
    - Under Frequency Mode
      - Knee Frequency (45 – 64Hz) **50Hz default**
      - Freq. Dev. From Knee Freq.(5Hz - fixed)
      - Slope #1 and #2 (0 – 10Hz) **2Hz default for both**
      - Min Voltage (50 – 100%) **50% default**
      - Min Frequency (20 – 40Hz) **25Hz default**
- Settings
  - Control Gain
    - PID Pre-Settings
      - 1 – 20 pre-programmed, 1 custom PID settings
      - PID Calculator
    - AVR
      - Kp, Ki, Kd (0 – 1000) **200/600/50 defaults**
      - Td (0 – 1s) **0 default**
      - Kg (0 – 1000) **50 default**
    - VAR/PF
      - Ki, Kg (1 – 1000) **5/2.5 & 5/3 defaults**
- PID Gains
  - PID Calculator

      - o T'do & Te required (**2.0 & 0.33s defaults**
      - o Adjust Kg to achieve desired response
  - Good generic values: PID = 80,20,10 then adj Kg as needed
  - var / PF Integral and Loop Gain Settings
      - o **Use factory defaults as a staring point**
      - o Increase Kg to increase speed of response (suggest keeping it slow)
      - o Increase Ki if var/PF regulation not acceptable
- o Protection
  - Shutdown Override (Enable to override shutdowns) **Disabled is default value**
      - o Function not affected:
          - Gen. Overvoltage
          - Gen. Undervoltage
          - Reverse VAR
          - Fault Reset too long
      - o Cannot be saved in EEPROM – Cycling power causes function to become disabled on power up
  - Generator Overvoltage (105 – 135%, 2 – 30s, **135%, 2s default**)
  - Generator Undervoltage (60 – 95%, 10 – 120s, **60%, 30s default**)
  - Over Excitation – Threshold is default (0 – 12A, **0 – 10s, 12A & 10s default**)
  - Over Excitation – Inv Time(0 – 12A, TD = 0 – 10, **12A & TD = 10 default**)
  - Reverse VAR (10 – 100%, 0.1 – 9.9s, **10% & 3s to be defaults soon**)
  - Fault Reset Too Long
  - Exciter Diode Monitor (1 – 10A, **2A default**)
  - Loss Of Sensing (0 – 25s, **2A default**)
- o Settings
  - Metering
      - o Gen Voltage
      - o Gen Current
      - o Gen Freq
      - o Gen Power
      - o Aux DC Input
      - o Exciter Field
      - o Operating Mode
      - o Fine Adjustment
      - o Setpoint
      - o Status
      - o Alarms
      - o Contact Inputs

Start/Stop Control

The ECM contains the logic and outputs for control of engine starting and shutdown. The customer programmable logic responds to signals from the engine control switch, emergency stop switch, remote start switch, data link and other inputs, and the ECM controls the starting motor, and the gas shutoff valve (GSOV) at the appropriate times.

Engine Monitoring and Protection

The ECM monitors both the engine operation and the electronic system. Any problems with the engine operation will cause the ECM to generate an event code that can either issue a warning or cause a shutdown, depending on the severity of the condition. Problems with the electronic system produce a diagnostic code that can be processed using the Cat ET service tool.

Integrated Temperature Sensing Module (ITSM)

The ITSM monitors the temperatures of the cylinder exhaust ports, the inlets of the turbocharger turbines, and the outlets of the turbocharger turbines.

If a temperature exceeds an acceptable range, the ITSM can initiate a warning or a shutdown. Both responses are available for all of the parameters.

Note: To initiate the responses, the ITSM sends commands to the ECM via the Cat Data Link.

The default settings for the parameters are programmed at the factory. To accommodate unique applications and sites, many of the parameters may be reprogrammed with the Cat ET service tool. The screens of the Cat ET provide guidance for the changing of trip points. The Cat ET can be used to perform the following activities:

- Select the available responses.
- Program the level of monitoring.
- Program delay times for each response.

Service Publications listed in the Reference Materials at the end of this section list default examples for the values of the parameters, however, the values may vary. The Cat ET service tool must be used to determine the programming for each specific engine.

G3600 Engine Protection System

Advanced Digital Engine Management (ADEM) A3 Control System

The Caterpillar Advanced Digital Engine Management (ADEM) A3 system is specifically designed for the G3600 Family of Caterpillar Engines. The ADEM A3 electronic controls integrate start/stop controls, governing, engine sensing/monitoring, air/fuel ratio control, ignition timing and detonation control into one comprehensive engine control system for optimum performance and reliability.

The ADEM A3 Control System includes the following components:

- Electronic Control Module (ECM) and emergency stop button in an engine mounted junction box
- Optional remote control panel with a Machine Information Display System (MIDS)
- Integrated Combustion Sensing Module (ICSM)
- Gas Shutoff Valve (GSOV)
- Ignition system controlled by ECM
- Detonation sensor for each two cylinders
- Prelube system that includes solenoid and prelube pump
- Electronically controlled hydraulic actuators for fuel, air choke and exhaust bypass (wastegate) (Hydrax)

G3600 ADEM A3 Control System

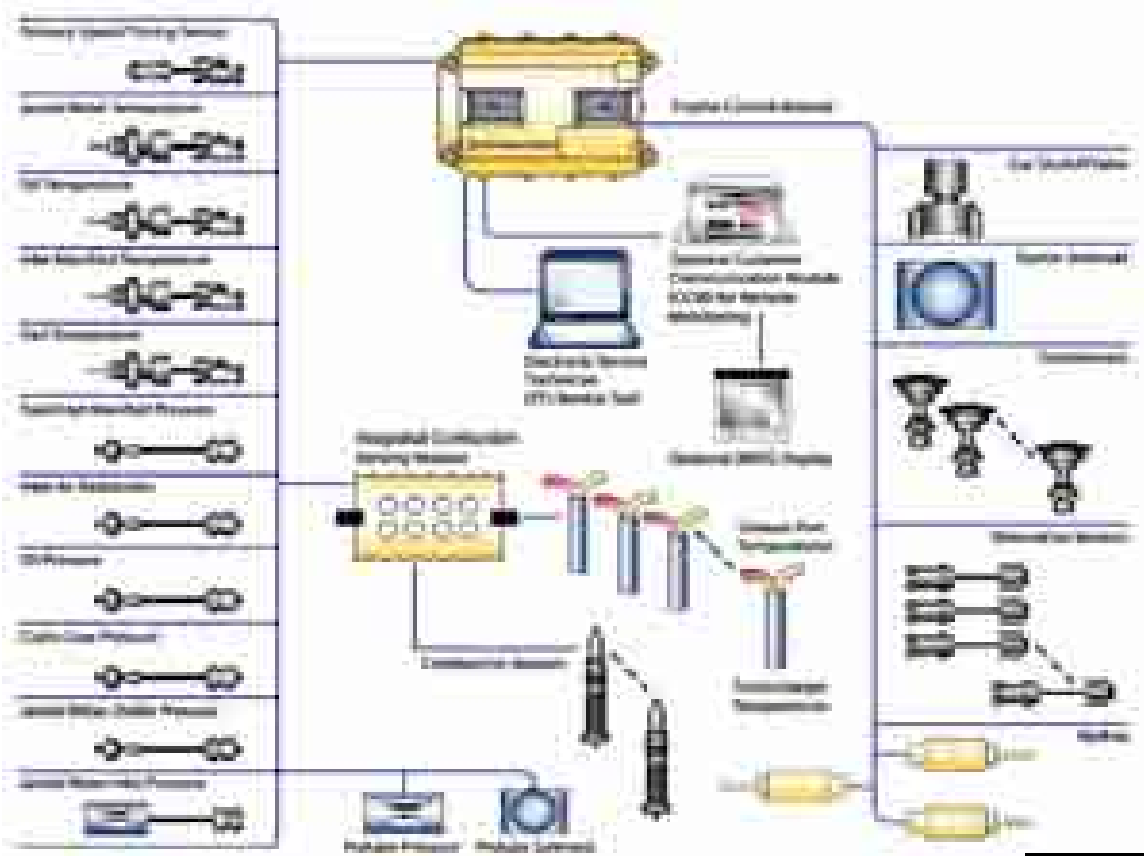

Figure 11

Electronic Control Module (ECM)

The Electronic Control Module (ECM) controls most of the functions of the engine. The module is an environmentally sealed unit that is in an engine-mounted junction box. The ECM monitors various inputs from sensors in order to activate relays, solenoids, etc. at the appropriate levels. The ECM supports the following five primary functions:

- Governing of the engine
- Control of ignition
- Air/fuel ratio control
- Start/stop control
- Engine monitoring and protection

The ECM control parameters are all preset at the factory with any site specific reprogramming done by Caterpillar service personnel during the commissioning process utilizing the Cat ET service tool. The following is a brief description of these five functions:

Governing of the Engine

The ECM monitors the actual engine speed, and calculates the difference between this and the desired engine speed. The ECM then adjusts the fuel flow by controlling the fuel actuator to maintain the desired engine speed.

The Hydrax actuator requires proper oil pressure to function reliably. Refer to service information listed in the Reference Material section for specifics.

Control of Ignition

Each cylinder has an ignition transformer. To initiate combustion, the ECM sends a pulse of approximately 108 volts to the primary coil of each ignition transformer at the appropriate time and for the appropriate duration. The transformer increases the voltage, which creates a spark across the spark plug electrode.

The ECM provides variable ignition timing that is sensitive to detonation. The detonation sensors (one for each two adjacent cylinders) monitor the engine for excessive detonation and provide this data to the ECM. If detonation reaches an unacceptable level, the ECM will retard the ignition timing of the affected cylinder or cylinders. If retarding the timing does not limit the detonation to an acceptable level, the ECM will shut down the engine.

A normal engine shutdown is accomplished by shutting off the fuel supply. The ignition system continues to operate until the engine is below 50 rpm. This allows the engine to consume the fuel that is trapped between the shutoff valve and the cylinder. The ignition system is disabled for engine overspeed and emergency stop shutdowns.

The ECM provides extensive diagnostics for the ignition system. The ECM also provides a switch for ignition timing in order to allow operation with alternate fuels that require a timing offset.

Levels of detonation can be displayed by the MIDS on the Optional Control Panel. Alternatively, the “Cylinder X Detonation Level” screen on the Cat ET service tool can also be used. The “X” represents the cylinder number.

Air/Fuel Ratio Control

The ECM provides control of the air/fuel mixture for performance and for efficiency at low emission levels utilizing the fuel actuator, air choke actuator, exhaust bypass actuator (wastegate), ICSM, thermocouples and combustion sensors. The system has five modes of operation for the air/fuel ratio:

- Start-up
- No feedback
- Exhaust port temperature feedback
- Combustion feedback
- Prechamber calibration

In each of these modes, the air/fuel ratio is controlled by either the air choke actuator or the wastegate actuator, but only one actuator operates at any time. Both of the actuators regulate air flow, and the active actuator is determined by the ability to provide the desired inlet manifold air pressure.

The software is also programmed to correct the fuel flow according to the temperature of the jacket water and the engine speed.

The modes of operation, their relationship to the engine load and the transitions between the modes are described in the Systems Operation documents listed in the Reference Materials at the end of this section. However, in general, at loads less than 40 percent, the air/fuel ratio is controlled by the air choke actuator. The air choke controls the flow of air during engine start-up, and continues to control the air flow during the increase of engine speed and load, until it becomes fully open. At this point, the wastegate becomes the active actuator.

Start/Stop Control

The ECM contains the logic and outputs for control of engine prelubrication, starting, shutdown and postlube. The customer programmable logic responds to signals from the engine control switch, emergency stop switch, remote start switch, data link and other inputs, and the ECM controls the prelube pump, the starting motor, and the gas shutoff valve (GSOV) at the appropriate times.

Engine Monitoring and Protection

The ECM monitors both the engine operation and the electronic system. Any problems with the engine operation will cause the ECM to generate an event code that can either issue a warning or cause a shutdown, depending on the severity of the condition. Problems with the electronic system produce a diagnostic code that can be processed using the Cat ET service tool.

Optional Control Panel

Figure 11 illustrates the optional control panel that is available as part of the ADEM A3 system.

Optional Control Panel

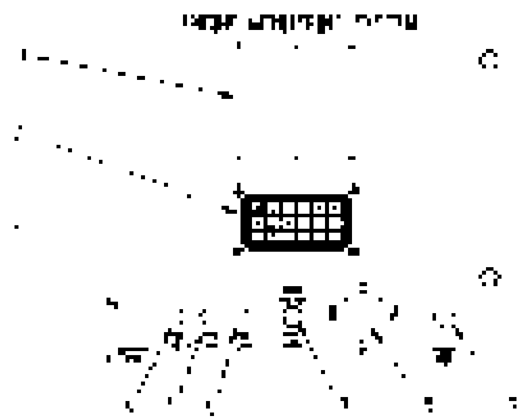

Figure 12

1. Display for the Machine Information Display System (MIDS).
30. Keypad for the MIDS.
31. "EMERGENCY STOP" button.
32. "ENGINE ON" indicator.
33. "ACTIVE ALARM" indicator.
34. "ENGINE FAILURE" indicator.
35. "MANUAL PRELUBE" switch and "PRELUBE ACTIVE" indicator.
36. Mode control switch.
37. "DESIRED SPEED" potentiometer.

Machine Information Display System (MIDS)

The MIDS is a device which enables the operator to monitor engine operation. The MIDS receives information from the ECM and is provided with a screen display and a keypad for operator interface; however, the MIDS cannot be used for programming.

Integrated Combustion Sensing Module (ICSM)

The ICSM monitors the temperatures of the cylinder exhaust ports, the inlets of the turbocharger turbines, and the outlets of the turbocharger turbines. The ICSM also monitors the combustion sensors.

If a temperature exceeds an acceptable range, the ICSM can initiate a warning or a shutdown. Both responses are available for all of the parameters.

Note: To initiate the responses, the ICSM sends commands to the ECM via the Cat Data Link.

The default settings for the parameters are programmed at the factory. To accommodate unique applications and sites, many of the parameters may be reprogrammed with the Cat ET service tool. The screens of the Cat ET provide guidance for the changing of trip points. The Cat ET can be used to perform the following activities:

- Select the available responses.
- Program the level of monitoring.
- Program delay times for each response.

Service Publications listed in the Reference Materials at the end of this section list default examples for the values of the parameters, however, the values may vary. The Cat ET service tool must be used to determine the programming for each specific engine.

Useful Equations from the Island Mode Sizing and Functionality

1.)

$$Generator\ Amps\ per\ Phase = \frac{Genset\ Rated\ Output\ (in\ Watts)}{\sqrt{3} \times Generator\ Output\ Voltage}$$

Example:

$$Generator\ Amps\ per\ Phase = \frac{2055000\ W\ Genset\ Rated\ Power}{\sqrt{3} \times 12470\ V} = 95.15\ Amps$$

2.)

$$Full\ Load\ CT\ Amps = \frac{Phase\ Amps}{CT\ Ratio}$$

Example:

$$Full\ Load\ CT\ Amps = \frac{95.15\ (Phase\ Amps)}{40\ (CT\ Ratio)} = 2.378\ (CT\ Full\ Output\ Amps)$$

3.)

$$Generator\ Volts\ per\ Phase = \frac{Generator\ Rated\ Voltage}{\sqrt{3}}$$

Example:

$$Generator\ Volts\ per\ Phase = \frac{12470\ (Generator\ Rated\ Voltage)}{\sqrt{3}} = 7199.8 Volts\ per\ Phase$$

4.)

$$PT\ Output\ Voltage = \frac{Volts\ per\ Phase}{PT\ Ratio}$$

Example

$$PT\ Output\ Voltage = \frac{12470\ (Volts\ per\ Phase)}{100\ (PT\ Ratio)} = 71.998 Volts\ (PT\ Full\ Output\ Volts)$$

Reference Material

The following information is provided as an additional reference to subjects discussed in this manual.

Operation and Maintenance Manuals

Systems Operation Manuals

Installation and Initial Start-up Procedures

Electrical System Schematics

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