EMCP 4 Integrated Voltage Regulator

Implementation Guide

Draft 00, Revision 08

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<td>details, Updated over-excitation event details</td>
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<tr>
<td>03/11/13</td>
<td>08</td>
<td>Revised starting and loading profile diagrams. Added</td>
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<td>information on EM fusing. Added torque requirements for</td>
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<td>EM mounting. Added detail to Reactive Droop and Line Loss Compensation sections.</td>
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1 General Information

1.1 INTRODUCTION

The EMCP Integrated Voltage Regulator (IVR) feature is a substitute for today’s voltage regulator topology consisting of a dedicated controller (CDVR, VR6...etc) for regulating voltage. The EMCP 4 internal controller regulates generator output voltage by sending a command to the Excitation Module (EM10/EM15) that controls generator excitation and therefore generator output voltage. This feature is available on EMCP 4.3 and EMCP 4.4 controllers, along with the new revised EMCP 4.1 and EMCP 4.2 controllers. This capability does NOT exist in the original EMCP 4.1 and EMCP 4.2 controllers.

The following guide describes the steps required to install and configure the Integrated Voltage Regulator software.

Include reference to EM Selection Chart

1.2 REFERENCES

1. LEBE0006: EMCP 4.1, 4.2 Generator Set Control, Application and Installation Guide

2. LEBE0007: EMCP 4.3, 4.4 Generator Set Control, Application and Installation Guide

3. LEBE0010: EMCP 4 SCADA Data Links, Application and Installation Guide

4. EM10 Spec Sheet

5. EM15 Spec Sheet
2 Important Safety Information

Most accidents that involve product operation, maintenance and repair are caused by failure to observe basic safety rules or precautions. An accident can often be avoided by recognizing potentially hazardous situations before an accident occurs. A person must be alert to potential hazards. This person should also have the necessary training, skills and tools to perform these functions properly.

Improper operation, lubrication, maintenance or repair of this product can be dangerous and could result in injury or death.

Do not operate or perform any maintenance or repair on this product, until you have read and understood the operation, maintenance and repair information.

Safety precautions and warnings are provided in this guide and on the product. If these hazard warnings are not heeded, bodily injury or death could occur to you or to other persons.

The hazards are identified by the “Safety Alert Symbol” and followed by a “Signal Word” such as “DANGER”, “WARNING” or “CAUTION”. The Safety Alert “WARNING” label is shown below.

The meaning of this safety alert symbol is as follows:

Attention! Become Alert! Your Safety is Involved.

The message that appears under the warning explains the hazard and can be either written or pictorially presented.

Operations that may cause product damage are identified by “NOTICE” labels on the product and in this publication.

Caterpillar cannot anticipate every possible circumstance that might involve a potential hazard. The warnings in this publication and on the product are, therefore, not all inclusive. If a tool, procedure, work method or operating technique that is not specifically recommended by Caterpillar is used, you must satisfy yourself that it is safe for you and for others. You should also ensure that the product will not be damaged or be made unsafe by the operation, lubrication, maintenance or repair procedures that you choose.

The information, specifications, and illustrations in this publication are on the basis of information that was available at the time that the publication was written. The specifications, torques, pressures, measurements, adjustments, illustrations, and other items can change at any time. These changes can affect the service that is given to the product. Obtain the complete and most current information before you start any job. Caterpillar dealers have the most current information available.
3 Hardware Installation

3.1 EMCP CONNECTIONS

The hardware installation detail provided in the following subsections is based on the assumption that the genset package is fitted with the revised EMCP 4.1 controller (CAT part number: 435-7931), revised EMCP 4.2 controller (CAT part number 431-1966), or an EMCP 4.3 or EMCP 4.4 genset controller.

To regulate the generator terminal voltage the EMCP communicates the desired excitation command to the Excitation Module via a PWM signal. It is recommended that twisted pair shielded cable is used for this communication link. Table 1 details the connections to be made between the EMCP and Excitation Module.

<table>
<thead>
<tr>
<th>EMCP 4.3, EMCP 4.4 120-Pin Connector</th>
<th>EMCP 4.1, EMCP 4.2 70-Pin Connector</th>
<th>Excitation Module 3-Pin Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWM Output#2 Positive  28</td>
<td>Digital Output #2 / IVR CS+  68</td>
<td>CS+  P3-2</td>
</tr>
<tr>
<td>PWM Output#2 Negative  8</td>
<td>Battery Negative Splice  60 or 65</td>
<td>CS-  P3-3</td>
</tr>
<tr>
<td>PWM Output#2 Shield  19</td>
<td>Battery Negative Splice  60 or 65</td>
<td>Shield  P3-1</td>
</tr>
</tbody>
</table>

Table 1 – EMCP Connections to Excitation Module

When replacement parts are required for this product Caterpillar recommends using Caterpillar replacement parts or parts with equivalent specifications including, but not limited to, physical dimensions, type, strength and material.

Failure to heed this warning can lead to premature failures, product damage, personal injury or death.
3.2 EXCITATION MODULE SPECIFICATION

The EM10 module is shown in Figure 1 and the EM15 in Figure 2.

![Figure 1 – EM10 Module](image1)

![Figure 2 – EM15 Module](image2)

Table 2 provides information on the technical specification of the EM10 and EM15 modules. Selection of the appropriate module should be determined by the nominal generator excitation current at full load (standby, 0.8PF), and the maximum input excitation voltage. Details on nominal field current are available in TMI or from the generator datasheet. Care must be taken on Self-Excited (shunt) generators to understand how the connections are being made from the winding to the excitation module in order to understand the maximum AC voltage input. It is recommended that an intermediate, half-phase connection is used for Self-Excited generators.

<table>
<thead>
<tr>
<th></th>
<th>EM10</th>
<th>EM15</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT Part Number:</td>
<td>398-7247</td>
<td>398-7248</td>
</tr>
<tr>
<td>Generator Excitation Type</td>
<td>Permanent Magnet (PM)</td>
<td>Self-Excitation (SE)</td>
</tr>
<tr>
<td>Nominal Field Current Output</td>
<td>6 Amps</td>
<td>7 Amps</td>
</tr>
<tr>
<td>Maximum (forcing) Field Current Output</td>
<td>10 Amps</td>
<td>15 Amps</td>
</tr>
<tr>
<td>Maximum AC Voltage Input</td>
<td>180 Vrms</td>
<td>240 Vrms</td>
</tr>
<tr>
<td>Exciter Field Resistance (recommended)</td>
<td>6 to 16 ohms</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 – Technical Specification of EM10 and EM15 modules
3.3 EXCITATION MODULE DIMENSIONS AND MOUNTING

It is recommended that the Excitation Module should be mounted within the genset control panel or the generator terminal box in landscape orientation in order to achieve optimum cooling from the module heat sink. The module should be fixed in place using 4 M6 x 30mm mounting bolts. The torque applied to the mounting bolts should be 5 N.m ± 1 N.m. It is recommended that an M6 washer (external diameter 12mm) is used with the mounting bolts to protect the module.

A dimensioned diagram of the EM10 module is presented in Figure 3. Note that the same dimensions also apply for the EM15 module.

![Figure 3 – EM10 Module Dimensions (in millimetres)]
3.4 EXCITATION MODULE CONNECTIONS

The EM10 and EM15 Excitation Modules have three multiple-pin, plug type connectors. These connectors are labelled “P2”, “P3” and “P4” as shown in Figure 3. Connector “P2” is a two-pin circuit board connector (header) that mates with a two-way socket Mate-N-Lok connector. Connector “P3” is a three-pin header that mates with a three-way socket Mate-N-Lok connector. Connector “P4” is a four-pin header that mates with a four-way socket Mate-N-Lok connector. It is recommended that a wire and interface seal are used with each of the Mate-N-Lok connectors to reduce the risk of moisture ingress and help ensure wire retention. Table 3 contains part number information on the recommended connectors, seals and contacts. For more information on splash-proof interface seal tooling and assembly please refer to Tyco Electronics Instruction Sheet 408-3392, 07 APR 11, Rev E. The recommended Mate-n-Lok female contact is a pre-tin phosphor bronze material which is selected based on the intended application.

<table>
<thead>
<tr>
<th>Description</th>
<th>AMP Part No.</th>
<th>CAT Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-way Mate-N-Lok Plug Housing</td>
<td>350777-1</td>
<td>416-1367</td>
</tr>
<tr>
<td>2-way Mate-N-Lok Interface Seal</td>
<td>794269-1</td>
<td>416-1332</td>
</tr>
<tr>
<td>2-way Mate-N-Lok Wire Seal</td>
<td>794270-1</td>
<td>416-1333</td>
</tr>
<tr>
<td>3-way Mate-N-Lok Plug Housing</td>
<td>350766-1</td>
<td>366-9370</td>
</tr>
<tr>
<td>3-way Mate-N-Lok Interface Seal</td>
<td>794271-1</td>
<td>416-1335</td>
</tr>
<tr>
<td>3-way Mate-N-Lok Wire Seal</td>
<td>794272-1</td>
<td>416-1334</td>
</tr>
<tr>
<td>4-way Mate-N-Lok Plug Housing</td>
<td>350779-1</td>
<td>351-9187</td>
</tr>
<tr>
<td>4-way Mate-N-Lok Interface Seal</td>
<td>794273-1</td>
<td>416-1336</td>
</tr>
<tr>
<td>4-way Mate-N-Lok Wire Seal</td>
<td>794274-1</td>
<td>416-1337</td>
</tr>
<tr>
<td>Mate-N-Lok Rigid Female Contact</td>
<td>350550-3</td>
<td>244-0452</td>
</tr>
</tbody>
</table>

Table 3 – Part Number Information for Mate-N-Lok connectors, seals and contacts

NOTE: Mate-N-Lok Rigid Female Contact CAT Part # 351-9188 is NOT compatible with using Wire Seals. To ensure a high quality crimp is achieved, the recommended AMP crimp tool should be used. Details of the recommended tooling are provided in Table 4.

<table>
<thead>
<tr>
<th>Description</th>
<th>AMP Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP Mate-N-Lok Crimp Tool Frame</td>
<td>354940-1</td>
</tr>
<tr>
<td>Die Set, 20/14AWG (1.52-3.3mm insul.)</td>
<td>90546-2</td>
</tr>
</tbody>
</table>

Table 4 – Tooling part number information for AMP Mate-N-Lok contact crimping
3.4.1 Connector P2

The illustration presented in Figure 4 shows the 2-way Mate-n-Lok circuit board connector P2 looking down at the module from above.

Figure 4 – Connector P2, 2-way Header

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Label</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2-1</td>
<td>F+</td>
<td>Exciter Field Positive Output</td>
</tr>
<tr>
<td>P2-2</td>
<td>F-</td>
<td>Exciter Field Negative Output</td>
</tr>
</tbody>
</table>

Table 5 – 2-way Connector Description

3.4.2 Connector P3

The illustration presented in Figure 5 shows the 3-way Mate-n-Lok circuit board connector P3 looking down at the module from above. The Shield pin is not connected to anything on the EM module and connecting of the shield at the EM side is therefore optional. The Shield should be connected to battery negative at only one end of the control signal link.

Figure 5 – Connector P3, 3-way Header

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Label</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3-1</td>
<td>Shield</td>
<td>Excitation Command Shield</td>
</tr>
<tr>
<td>P3-2</td>
<td>CS+</td>
<td>Excitation Command Positive Input</td>
</tr>
<tr>
<td>P3-3</td>
<td>CS-</td>
<td>Excitation Command Negative Input</td>
</tr>
</tbody>
</table>

Table 6 – 3-way Connector Description
3.4.3 Connector P4

The illustration presented in Figure 6 shows the 4-way Mate-n-Lok circuit board connector P4 looking down at the module from above.

![Connector P4, 4-way Header](image)

**Figure 6 – Connector P4, 4-way Header**

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Label</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>P4-1</td>
<td>X2</td>
<td>Excitation Power Supply Input X2</td>
</tr>
<tr>
<td>P4-2</td>
<td>Z1</td>
<td>Excitation Power Supply Input Z1</td>
</tr>
<tr>
<td>P4-3</td>
<td>X1</td>
<td>Excitation Power Supply Input X1</td>
</tr>
<tr>
<td>P4-4</td>
<td>Z2</td>
<td>Excitation Power Supply Input Z2</td>
</tr>
</tbody>
</table>

**Table 7 – 4-way Connector Description**

Note that connections X2 and Z1 are internally linked within the EM, providing a point of common connection for the auxiliary windings where an AREP/IE excitation supply is available. Alternatively, connections X2 and Z1 may be linked external to the EM, and only three connections made to the device (X1, X2 and Z2). Three and four-wire AREP/IE connection diagrams are provided in Appendix A.
3.5 EXCITATION MODULE OVER-EXCITATION PROTECTION

The Excitation Module has a built-in over-excitation protection strategy that is designed to protect the generator from thermal damage. The protection strategy employed is illustrated in Figure 7.

Under normal conditions the excitation current will remain well below the upper limit and the GREEN LED on the Excitation Module will be lit continuously.

In the event of a fault condition, for example during a short-circuit on the generator terminals, the excitation current will increase rapidly, known as ‘field forcing’. The Excitation Module will limit the forcing current to the defined upper limit for a fixed period of 10 seconds. When the Excitation Module is actively limiting the field current a RED LED will flash indicating a fault condition. After the fixed delay time has expired, the Excitation Module will ‘shut down’ the excitation current to a safer level that is 10% of the upper limit. When the Excitation Module has shut down the excitation current, the RED LED is lit continuously and the GREEN LED is not lit. The RED LED will be lit only while voltage is being supplied to the Excitation Module. In order to reset the excitation current limiting the excitation current, the power supply must be removed from the Excitation Module by shutting down the genset.

Figure 7 – Over-excitation protection strategy implemented within the Excitation Module
The Excitation Limit Potentiometer on the Excitation Module has 270 degrees of rotation and is used to configure the Excitation Current Upper Limit as shown in Figure 8. Keep in mind that this must be set for maximum forcing current, and not nominal excitation current.

![Excitation Limit Potentiometer](image)

<table>
<thead>
<tr>
<th></th>
<th>EM10</th>
<th>EM15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Position</td>
<td>4 Amps</td>
<td>6 Amps</td>
</tr>
<tr>
<td>Maximum Position</td>
<td>10 Amps</td>
<td>15 Amps</td>
</tr>
</tbody>
</table>

**Figure 8** – Maximum and Minimum Limits of Excitation Limit Potentiometer

### 3.6 EXCITATION MODULE FUSING

The EM10 has internal fusing, therefore it is not necessary to fit external fuses on the excitation power supply inputs.

The EM15 requires external fusing to be fitted on inputs X1, X2 and Z2. The recommended fuse for UL listed gensets is a Bussman KTK-10 (Cat part number 6V7802). For non-UL listed gensets an alternative fuse is Bussman AGC-10RX (Cat part number 3K8782).

Connection diagrams showing the location of external fusing on the EM15 are provided in Appendix A.

### 3.7 EXCITATION MODULE SELECTION

Based on the technical specifications for each Excitation Module detailed in Section 3.2, the recommended Excitation Module selection for each generator frame/series is detailed in Table 8.

<table>
<thead>
<tr>
<th>Generator Frame / Series</th>
<th>Recommended Excitation Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC1100</td>
<td>EM10</td>
</tr>
<tr>
<td>LC1500</td>
<td>EM10</td>
</tr>
<tr>
<td>LC3000</td>
<td>EM10</td>
</tr>
<tr>
<td>LC5000</td>
<td>EM10</td>
</tr>
<tr>
<td>LC6100</td>
<td>EM10</td>
</tr>
<tr>
<td>LC7000</td>
<td>EM10</td>
</tr>
</tbody>
</table>

**Table 8** – Recommended Excitation Module by Generator Frame/Series

Reference table to be updated with SR5 data
4 IVR Setpoint Configuration

The Integrated Voltage Regulator parameters can be accessed using either the CAT ET Service tool, or directly through the EMCP display. Some setpoints are locked at ET only or at Security Level 3 and cannot be changed from the EMCP display or will require a level 3 password. Please note that ET Service Tool version 2012C or later is recommended for accessing and adjusting IVR parameters.

To access the Integrated Voltage Regulator setpoints using the ET Service Tool, connect to the EMCP Genset Control and click on the ‘Configuration Tool’ button (alternatively press F5) to enter the configuration menu. Select ‘Integrated Voltage Regulator’ from the menu on the left and set Voltage Regulator Control Source Configuration equal to ‘Genset Control’ to display the following default settings:

To access the Integrated Voltage Regulator setpoints through the EMCP display, navigate to the following sub-menu:

MAIN MENU
CONFIGURE
ALL SETPOINTS
INTEGRATED VOLTAGE REGULATOR

If replacing a CDVR with IVR, the parameters should be programmed exactly the same as CDVR in order to achieve the same performance. If the IVR is a new installation, or a R450 or VR6 voltage regulator is being replaced, the parameters can be programmed to the default values with a low loop gain starting in the region 5.0%-10.0%. Note that the default parameters should provide stable voltage control for most gensets, however some optimization and tuning may be required to achieve the desired performance. The following subsections provide further detail on each individual setpoint, including range, resolution and default values.
4.1.1 Voltage Regulator Control Source Configuration

<table>
<thead>
<tr>
<th>Name</th>
<th>Options</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Control Source Configuration</td>
<td>0 = External Control</td>
<td>0 (External Control)</td>
<td>ET Service Tool Only</td>
</tr>
<tr>
<td></td>
<td>1 = Genset Control</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Voltage Regulator Control Source Configuration parameter is used to enable or disable the Integrated Voltage Regulator feature.

- If set to ‘External’ the Integrated Voltage Regulator feature of the EMCP is disabled and the genset can run with an external voltage regulator, for example, CDVR, R450, VR6, etc.

- If set to ‘Genset Control’ the Integrated Voltage Regulator feature of the EMCP is enabled and the genset will run using an Excitation Module.

Note that this parameter will only change state if the genset is stopped (stop button pressed and engine speed 0 rpm), and can only be changed via ET, and not directly through the EMCP display.

WARNING

It is important that the Voltage Regulator Control Source Configuration is correctly programmed BEFORE starting the genset. In the case where an external voltage regulator is used, if Voltage Regulator Control Source Configuration is set to ‘Genset Control’, there is a risk of nuisance triggering of IVR-related warning and shutdown events. In the case where IVR is to be used but the Voltage Regulator Control Source Configuration is set to ‘External’, there is a risk that the PWM output may float high causing the Excitation Module to force the excitation current to the upper limit and risking damage to the generator.
### 4.1.2 Starting Profile

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Units</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Starting Voltage Percent</td>
<td>0.0</td>
<td>90.0</td>
<td>0.1</td>
<td>%</td>
<td>10.0</td>
<td>ET Service Tool or EMCP Display</td>
</tr>
<tr>
<td>Voltage Regulator Starting Time</td>
<td>0.0</td>
<td>60.0</td>
<td>0.1</td>
<td>seconds</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

The starting profile setpoints defined above are used to determine the slope of the voltage ramp when starting the genset.

If the Voltage Regulator Starting Voltage Percent is zero, the Voltage Regulator Starting Time defines the time to reach the rated voltage setpoint from the point that the frequency exceeds the Voltage Regulator Minimum Frequency Threshold. An example Starting Profile with Voltage Regulator Starting Voltage Percentage set to 0% and Voltage Regulator Starting Time set to 5 seconds is illustrated in Figure 9.

![Starting Profile Diagram](image)

**Figure 9** – Starting Profile with Voltage Regulator Starting Voltage Percent set to 0% and Voltage Regulator Starting Time set to 5 seconds
If the Voltage Regulator Starting Voltage Percent is non-zero, the Voltage Regulator Starting Time defines the time to get to the rated voltage setpoint from the point that the Voltage Regulator Starting Voltage Percent is reached by following the programmed Volts/Hz slope. An example Starting Profile with Voltage Regulator Starting Voltage Percentage set to 10% and Voltage Regulator Starting Time set to 3 seconds is illustrated in Figure 10.

![Graph](image)

**Figure 10** – Starting Profile with Voltage Regulator Starting Voltage Percent set to 10% and Voltage Regulator Starting Time set to 3 seconds

A further example with Voltage Regulator Starting Voltage Percentage set to 90% and Voltage Regulator Starting Time set to 3 seconds is illustrated in Figure 11.
If the Voltage Regulator Starting Time is set to zero, or the engine has a slow starting ramp, the Integrated Voltage Regulator will follow the programmed Volts/Hz slopes. The voltage setpoint during starting is therefore the minimum of the Starting Profile setpoint and the Under-Frequency Roll-Off (Loading) Profile setpoint.

In order to avoid a large voltage overshoot during starting, particularly on generators with Shunt or AREP excitation systems, the Excitation Command output from the EMCP is limited to a maximum value of 20% during starting. This prevents integral windup within the PID controller in the case where, during starting, there is insufficient residual voltage at the generator output to build excitation. **The 20% limit is removed once the output voltage exceeds the Minimum Voltage Setpoint Percentage.**

Once the frequency exceeds the Voltage Regulator Corner <Knee> Frequency threshold and the nominal voltage setpoint has been reached, the Integrated Voltage Regulator will follow the Under-Frequency Roll-Off (Loading) Profile. The Starting Profile will not be initiated again until the frequency drops below the Voltage Regulator Minimum Frequency Threshold.
4.1.3 PID Gain Setpoints

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Units</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Loop Gain</td>
<td>0.00</td>
<td>100.00</td>
<td>0.01</td>
<td>%</td>
<td>5.00</td>
<td>ET Service Tool or EMCP Display</td>
</tr>
<tr>
<td>Percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Proportional</td>
<td>0.00</td>
<td>100.00</td>
<td>0.01</td>
<td>%</td>
<td>20.00</td>
<td>ET Service Tool Only (Level 3 Password)</td>
</tr>
<tr>
<td>Gain Percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Integral</td>
<td>0.00</td>
<td>100.00</td>
<td>0.01</td>
<td>%</td>
<td>60.00</td>
<td>ET Service Tool Only (Level 3 Password)</td>
</tr>
<tr>
<td>Gain Percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Derivative</td>
<td>0.00</td>
<td>100.00</td>
<td>0.01</td>
<td>%</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Gain Percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Noise Filter</td>
<td>0.00</td>
<td>1.00</td>
<td>0.01</td>
<td>Seconds</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Time Constant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The PID gain setpoints can be tuned to achieve the desired voltage response depending on the application and genset configuration. The default parameters have been selected to provide stable voltage control on most generators, however some optimisation may be required.

If the voltage regulation appears unstable, it may be necessary to reduce the Voltage Regulator Loop Gain Percentage to achieve stability. As a guideline, decreasing in steps of 0.5-1.0% is generally sufficient to observe a noticeable improvement.

If the voltage response appears sluggish, it is recommended to increase the Voltage Regulator Loop Gain Percentage to achieve the desired response. Increasing in steps of 0.5-1.0% is generally sufficient to observe a noticeable improvement.

Please refer to the Integrated Voltage Regulator PID Tuning Guide section of the manual (Section 5) for further information on optimising the controller gains for best performance.
4.1.4 Under-Frequency Roll-Off (Loading) Profile

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Units</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Corner &lt;Knee&gt; Frequency</td>
<td>45.0</td>
<td>65.0</td>
<td>0.1</td>
<td>Hz</td>
<td>48.0</td>
<td>ET Service Tool</td>
</tr>
<tr>
<td>Voltage Regulator Deviation From Corner &lt;Knee&gt; Frequency</td>
<td>0.0</td>
<td>10.0</td>
<td>0.1</td>
<td>Hz</td>
<td>5.0</td>
<td>EMCP Display</td>
</tr>
<tr>
<td>Voltage Regulator Volts/Hz Slope 1</td>
<td>0.0</td>
<td>10.0</td>
<td>0.1</td>
<td>Volts/Hz</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Volts/Hz Slope 2</td>
<td>0.0</td>
<td>10.0</td>
<td>0.1</td>
<td>Volts/Hz</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Minimum Voltage &lt;Setpoint&gt; Percentage</td>
<td>30</td>
<td>100</td>
<td>1</td>
<td>%</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Minimum Frequency Threshold</td>
<td>20</td>
<td>40</td>
<td>1</td>
<td>Hz</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

The ‘Voltage Regulator Knee Frequency’ needs to be configured for your specific package requirements. The Knee Frequency for 50Hz operation will usually be between 48.0 and 49.8Hz, whereas for 60Hz operation this parameter should be set between 58.0 to 59.8 Hz.

An example Under-Frequency Roll-Off (Loading) Profile is illustrated in Figure 12.

Figure 12 – Example Under-Frequency (Loading) Profile, Slope1 = 1.0 V/Hz, Slope2 = 2.0 V/Hz
4.1.5 Voltage Regulator Load Compensation Type Configuration

<table>
<thead>
<tr>
<th>Name</th>
<th>Options</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
</table>
| Voltage Regulator Load Compensation Type Configuration | 0 = OFF  
1 = IR Compensation  
2 = Voltage Droop | 0             | ET Service Tool or EMCP Display |

The load compensation features of IR Compensation and Voltage Droop are explained in Sections 4.1.6 and 4.1.7 respectively.

**NOTE:** IR Compensation and Voltage Droop are mutually exclusive features designed for different applications, therefore it is not possible to enable both compensation types at the same time.

4.1.6 Line Loss (IR) Compensation

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Units</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Voltage (IR) Compensation Percentage</td>
<td>0.0</td>
<td>10.0</td>
<td>0.1</td>
<td>%</td>
<td>0.0</td>
<td>ET Service Tool or EMCP Display</td>
</tr>
</tbody>
</table>

In some installations where a single generator is used with long feeder lines to the load, it may be advantageous to provide line loss compensation. Line loss compensation is commonly referred to as IR compensation.

Current flowing through a long conductor causes a voltage drop due to the resistance of the wire. Therefore, the voltage at the load end of the conductor will be lower than the voltage at the generator end due to the voltage drop along the conductor. This condition is commonly referred to as line loss. In order to improve the power quality the IVR can compensate for this phenomenon. As generator load increases, the IVR will increase the output voltage at the generator terminals in order to compensate for line losses. The Voltage Regulator Voltage (IR) Compensation Percentage setpoint controls the quantity of voltage compensation at the rated kVA load. It should be adjusted to yield a constant voltage at the location of the load.

For example, if it is observed that the voltage at the load side of the feeder line has decreased by 5% from rated voltage when the generator is supplying rated kVA load, the Voltage Regulator (IR) Compensation Percentage should be set to 5.0%. In this case, the output voltage measured at the generator terminals will increase from 100% to 105% of rated voltage as the generator load increases from 0% to 100% of rated kVA, as illustrated in Figure 13.

If a bias is applied to the voltage setpoint from an external source, the IR compensation percentage is applied to the nominal setpoint plus the bias percentage. For example, if a +10% or -10% bias were applied to the nominal voltage, the voltage setpoint would increase linearly as shown by the Upper and Lower Bias Limit dashed lines indicated on the diagram presented in Figure 13.
NOTE: It is important that the capability of the machine is not exceeded during operation.

### 4.1.7 Reactive Droop Compensation

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Units</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Maximum Droop Percentage</td>
<td>0.0</td>
<td>10.0</td>
<td>0.1</td>
<td>%</td>
<td>0.0</td>
<td>ET Service Tool or EMCP Display</td>
</tr>
</tbody>
</table>

When generators operate in parallel, two primary objectives are for the generators to share both the real power requirements and the reactive power requirements of the system electrical load. The engine governors will control sharing of the real power requirements (kW) and the voltage regulators will control sharing of the reactive power requirements (kVAR) of the total system load. When one or more generators are connected in parallel, the voltage measured at the output terminals of each generator will be the same. However, if the voltage setpoint of one generator is slightly higher than the other generators, it will increase excitation in an attempt to raise the system voltage and in doing so will supply lagging reactive current to the other generators connected in the group. This current will circulate between generators, causing excessive heating of the generator windings and an increased risk of thermal damage. One method of minimizing this effect is to cause an individual generator’s voltage setpoint to sag, or “droop”, in proportion to its’ reactive power output. For proper reactive load sharing, the regulator must know the rated generator reactive power (kVAR), which is calculated from

---

Figure 13 – Line Loss voltage setpoint change based on total (kVA) load
the genset rated kVA and kW, and the desired percentage of output voltage droop when the generator is supplying rated reactive power.

As the reactive power output increases, the IVR will cause the output voltage to droop (reduce the voltage) proportionally. If the measured reactive power output is leading, the output voltage will rise in the same linear fashion. In either case, this action will tend to support better kVAR sharing with other generators. Note that it is important that the generator operation remains within its capability.

The Voltage Regulator Maximum Droop Percentage setpoint controls how much the generator output voltage will vary for a given amount of reactive power output. For example, if the Maximum Droop Percentage is set to 5.0%, the voltage setpoint will droop from 100% to 95% of rated voltage as the reactive power output increases from 0% to 100% of rated kVAR (lagging). This is illustrated in the diagram presented in Figure 14.

If a bias is applied to the voltage setpoint from an external source, the reactive droop percentage is applied to the nominal setpoint plus the bias percentage. For example, if a +10% or -10% bias were applied to the nominal voltage, the voltage setpoint would droop as shown by the Upper and Lower Bias Limit dashed lines indicated on the diagram presented in Figure 14.

**Figure 14** – Reactive Droop voltage setpoint change based on reactive (kVAR) load

**NOTE:** It is important that the capability of the machine is not exceeded during operation.
4.1.8 Voltage Regulator Lockout Configuration

<table>
<thead>
<tr>
<th>Name</th>
<th>Options</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
</table>
| Voltage Regulator Lockout Configuration | 0 = Not Locked Out  
1 = Locked Out          | 0.0                      | ET Service Tool Only |

When Voltage Regulator Lockout Configuration is set to ‘Not Locked Out’, the Integrated Voltage Regulator will operate normally and control the generator voltage output to the reference setpoint.

When Voltage Regulator Lockout Configuration is set to ‘Locked Out’, the Integrated Voltage Regulator will be prevented from controlling the generator voltage output and the Excitation Command output will remain at zero. Excitation is therefore disabled in this scenario, and the generator will only produce residual voltage.

The Voltage Regulator Lockout Configuration setpoint can only be changed when the genset is STOPPED (EMCP stop button pressed) and engine speed equals zero.

4.1.9 Loss of Sensing Shutdown Event

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Units</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Loss Of Sensing Shutdown Event Notification Delay Time</td>
<td>0.0</td>
<td>25.0</td>
<td>0.1</td>
<td>Seconds</td>
<td>2.0</td>
<td>ET Service Tool or EMCP Display</td>
</tr>
</tbody>
</table>

The Voltage Regulator Loss Of Sensing Shutdown Event Notification Delay Time determines the time delay between when a loss of sensing voltage is recognized and when a Loss of Sensing Shutdown event (SPN-FMI: 611-0) is generated. Based on average line-to-line voltage monitoring, loss of sensing is triggered under the following conditions:

For Single Phase configuration: Average line-to-line voltage < 8% of rated

For Three Phase configuration:
- Balanced three phase average < 8% of rated OR
- Imbalance between a line quantity and three phase average > 20% of rated OR
- Loss of a phase (line-to-neutral voltage < 8% of rated).

The Loss of Sensing Shutdown event is inhibited when
- a generator short circuit condition is detected (any phase current exceeds 300% of rated)  
- during voltage starting profile (IVR operating mode equals SOFT START) 
- for 5 seconds after frequency increases above the Voltage Regulator Minimum Frequency Threshold setpoint 
- when excitation is disabled (Voltage Regulator Lockout Configuration is set to ‘Locked Out’)

Caterpillar: Confidential Yellow

IVR Implementation Guide- Rev. 08
4.1.10 Over Excitation Shutdown Event

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Units</th>
<th>Default Value</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Regulator Over Excitation Shutdown Event</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.0</td>
<td>ET Service Tool or EMCP Display</td>
</tr>
<tr>
<td>Threshold</td>
<td>10</td>
<td>100</td>
<td>1</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Regulator Over Excitation Shutdown Event</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Event Notification Delay Time</td>
<td>0.1</td>
<td>20.0</td>
<td>0.1</td>
<td>Seconds</td>
<td>10.0</td>
<td></td>
</tr>
</tbody>
</table>

The Over Excitation Shutdown Event Threshold configuration determines the percentage of excitation command that will cause an Over Excitation Shutdown event. If the excitation command percentage exceeds the Over Excitation Shutdown Event Threshold for longer than the Over Excitation Shutdown Event Notification Delay Time an Over Excitation Shutdown event (SPN-FMI: 3381-0) will be generated.

**NOTE:** The Over Excitation Shutdown event monitors and triggers an event based on Excitation Command Percentage and does NOT trigger based on measured excitation current. See section 3.5 Excitation Module Over-Excitation Protection for a description of the Excitation Module over-excitation protection feature that is based on measured excitation current.

4.2 VOLTAGE ADJUSTMENT

Voltage adjustments are categorized into two types: Manual biasing and Analog biasing. Manual voltage adjustment includes fine tuning the generator output voltage via digital input, EMCP display or SCADA (Modbus). Analog voltage adjustment is performed via programmable analog inputs to the EMCP and provide a voltage control interface for external potentiometers or external control systems (such as switchgear).

It is important to note that the setpoint Gen Maximum Voltage Bias Percentage must be correctly configured to be greater than the expected bias range, otherwise it may not be possible to achieve the required voltage bias. The parameter Gen Maximum Voltage Bias Percentage is accessed within the CAT ET Service Tool configuration menu under Generator AC Monitor, or can be accessed from the EMCP display by navigating to the following sub-menu:

**MAIN MENU**

CONFIGURE

ALL SETPOINTS

GEN AC MONITOR

**NOTE:** All manual voltage biasing is removed and reset to zero when the engine is stopped. Manual voltage bias levels are not carried over to the next start up after an engine shutdown.
4.2.1 Digital Inputs

Remote voltage adjustment toggle switches may be used to fine tune the generator output voltage by programming an EMCP digital input for Raise Voltage and Lower Voltage. Each activation of the digital input raises or lowers the voltage by 0.2% of rated. When the digital input is activated continuously, the voltage bias is raised or lowered by 0.2% of rated approximately every 400ms.

Refer to EMCP 4.1, 4.2 Generator Set Control, Application and Installation Guide (LEBE0006) and EMCP 4.3, 4.4 Generator Set Control, Application and Installation Guide (LEBE0007) for further details on programming digital inputs on EMCP 4 controllers.

4.2.2 Voltage / Hz Control (EMCP Display)

The EMCP display may be used to fine tune the generator output voltage. Each press of the voltage raise or voltage lower key raises or lowers the voltage by 0.2% of rated voltage. When the voltage raise or voltage lower key is pressed and held continuously, the voltage bias is raised or lowered by 0.2% of rated approximately every 400ms.

The Voltage / Hz Control screen can be found on the EMCP display by navigating to the following submenu:

MAIN MENU
CONTROL
VOLTAGE / Hz CONTROL

![Figure 15 – EMCP 4.2, EMCP 4.3, and EMCP 4.4 Voltage / Hz Control Screen](image)

4.2.3 SCADA (Modbus)

EMCP 4 SCADA data links also provide a means for adjusting voltage remotely. EMCP 4 modbus registers are defined for reading and controlling the target output voltage of the generator. Refer to EMCP 4 SCADA Data Links Application and Installation Guide (LEBE0010) for more details on EMCP 4 dedicated SCADA data links.
4.2.4 Analog Inputs

Analog voltage adjustment is done via a programmable analog input to the EMCP configured for Generator Voltage Control. Analog inputs provide a voltage control interface for external potentiometers or external control systems (such as switchgear). The following analog input types can be configured on an EMCP 4.1 or EMCP 4.2 to adjust the generator voltage setpoint:

- Resistive (a range of input maps are available depending on the potentiometer size)
- Voltage
  - 0 to 5 V
  - 1 to 5 V
  - 0.5 to 4.5 V

The following analog input types can be configured on an EMCP 4.3 and EMCP 4.4 to adjust the generator voltage setpoint:

- Resistive (a range of input maps are available depending on the potentiometer size)
- PWM
  - 0 to 100%
  - 5 to 95%
- Current
  - 0 to 20 mA
  - 4 to 20 mA
  - 0 to 10 mA
- Voltage
  - 0 to 5 V
  - 1 to 5 V
  - 0 to 10 V
  - -3 to +3 V
  - -2.5 to +2.5 V
  - -5 to +5 V
  - -10 to +10 V
  - 0.5 to 4.5 V
  - -1 to +1 V

The Generator Voltage Control analog input signal is interpreted and converted by the EMCP into a voltage bias percentage of (nominal) rated voltage. For example, consider an analog input configured for a signal range of -10 to +10 V and a data range of -10% to 10%. When this analog input signal value equals +2 V, a voltage bias percentage of +2.0% of rated will be applied to the generator output voltage.

Refer to EMCP 4.1, 4.2 Generator Set Control, Application and Installation Guide (LEBE0006) and EMCP 4.3, 4.4 Generator Set Control, Application and Installation Guide (LEBE0007) for further details on programming analog inputs on EMCP 4 controllers.
5 Integrated Voltage Regulator PID Tuning Guide

Information to be added to this section on optimising the PID tuning parameters – next release.

6 EMCP IVR Overview Display Screens

The Integrated Voltage Regulator Overview and Voltage Bias Overview can be accessed directly through the EMCP display. To access the IVR Overview and Voltage Bias Overview through the EMCP display, navigate to the following sub-menus:

MAIN MENU
   VIEW
      IVR OVERVIEW
      VOLTAGE BIAS OVERVIEW

The IVR Overview screen provides IVR operating mode, target voltage, excitation command and voltage compensation information. The Voltage Bias Overview screen provides information on all active voltage biasing on the generator system.

6.1 EMCP 4.1 AND EMCP 4.2 CONTROLS

The IVR Overview screen on the EMCP 4.1 and EMCP 4.2 displays the IVR operating mode, target voltage, and excitation command percentage.

NOTE: Excitation command percentage is NOT a measurement of excitation current, but rather a commanded excitation operating point. A non-zero excitation command percentage MAY be displayed on screen even during a fault scenario resulting in zero excitation current output.

![IVR Overview Screen Screenshot]

Figure 16 – EMCP 4.1 and EMCP 4.2 IVR Overview Screens
The IVR operating modes for EMCP 4.1 and EMCP 4.2 are described below:

- **VOLTS/Hz** – voltage is regulated according to the under frequency roll off (Volts/Hz) profile described in section 4.1.4 Figure 12.
- **V/Hz + DROOP** – voltage is regulated according to the under frequency roll off (Volts/Hz) profile described in section 4.1.4 in addition to any reactive droop compensation bias described in section 4.1.7
- **V/Hz + LINE LOSS** - voltage is regulated according to the under frequency roll off (Volts/Hz) profile described in section 4.1.4 in addition to any line loss (IR) compensation bias described in section 4.1.6
- **SOFT START** – voltage is ramped during start up from 0 voltage to rated voltage according to the starting profile described in section 4.1.2
- **IVR LOCKED OUT** - voltage regulation is locked out and the excitation command is disabled (forced to 0 %). Generator output voltage will not build beyond residual voltage.
- **PF CONTROL** – voltage regulation is performed in order to control power factor to a desired level (EMCP 4.2, EMCP 4.3, and EMCP 4.4 only)
- **STOPPING** – voltage is ramped down in proportion to engine speed during shutdown.

The Voltage Bias Overview screen on the EMCP 4.1 and EMCP 4.2 displays manual, analog, load compensation and total voltage bias percentages applied to the generator output.

![Voltage Bias Overview](image)

The voltage biasing information for EMCP 4.1 and EMCP 4.2 is described below:

- **MANUAL** – summation of any voltage bias applied via programmable digital input, Voltage / Hz Control screen on the EMCP display or SCADA (Modbus) voltage bias.
- **ANALOG** – any voltage bias applied via a programmable analog input described in section 0.
- **DROOP** or **LINE LOSS** – any voltage bias applied as a result of reactive droop or line loss load compensation described in section 4.1.5. (EMCP 4.2, EMCP 4.3 and EMCP 4.4 only)
- **TOTAL** – total voltage bias applied to the generator system. This total percentage bias is the summation of any manual, analog, or compensation (droop or line loss) biasing in the system.

**NOTE:** The total percentage bias that can be applied to the generator system is limited by the Maximum Generator Voltage Output Bias Percentage setpoint configured in the EMCP.
### 6.2 EMCP 4.3 AND EMCP 4.4 CONTROLS

The IVR Overview screen on the EMCP 4.3 and EMCP 4.4 displays the IVR operating mode, target voltage, load compensation type, and excitation command percentage.

**NOTE**: Excitation command percentage is NOT a measurement of excitation current, but rather a commanded excitation operating point. A non-zero excitation command percentage MAY be displayed on screen even during a fault scenario resulting in zero excitation current output.

![IVR Overview Screen](image)

**Figure 18** – EMCP 4.3 and EMCP 4.4 IVR Overview screen

The IVR operating modes for EMCP 4.3 and EMCP 4.4 are described below:

- **VOLTS/Hz** – voltage is regulated according to the under frequency roll off (Volts/Hz) profile described in section 4.1.4 and Figure 12.
- **V/Hz + DROOP** – voltage is regulated according to the under frequency roll off (Volts/Hz) profile described in section 4.1.4 and Figure 12 in addition to any reactive droop compensation bias described in section 4.1.7
- **V/Hz + LINE LOSS** – voltage is regulated according to the under frequency roll off (Volts/Hz) profile described in section 4.1.4 and Figure 12 in addition to any line loss (IR) compensation bias described in section 4.1.6
- **SOFT START** – voltage is ramped during start up from 0 voltage to rated voltage according to the starting profile described in section 4.1.2
- **IVR LOCKED OUT** – voltage regulation is locked out and the excitation command is disabled (forced to 0 %). Generator output voltage will not build beyond residual voltage.
- **SYNCHRONIZING** – voltage regulation is performed in order to synchronize generator voltage with bus voltage in paralleling operation (EMCP 4.4 only)
- **PF CONTROL** – voltage regulation is performed in order to control power factor to a desired level (EMCP 4.2, EMCP 4.3, and EMCP 4.4 only)
- **kVAR SHARING** – voltage regulation is performed in order to maintain reactive load sharing levels in paralleling operation (EMCP 4.4 only)
- **STOPPING** – voltage is ramped down in proportion to engine speed during shutdown.

The Voltage Bias Overview screen on the EMCP 4.3 and EMCP 4.4 displays manual, analog, load compensation and total voltage bias percentages applied to the generator output.
The voltage biasing information for EMCP 4.3 and EMCP 4.4 is described below:

- **MANUAL** – summation of any voltage bias applied via programmable digital input, Voltage / Hz Control screen on the EMCP display or SCADA (modbus) voltage bias.
- **ANALOG** – any voltage bias applied via a programmable analog input described in section 0.
- **DROOP or LINE LOSS** – any voltage bias applied as a result of reactive droop or line loss load compensation described in section 4.1.5. (EMCP 4.2, EMCP 4.3 and EMCP 4.4 only)
- **TOTAL BIAS** – total voltage bias applied to the generator system. This total percentage bias is the summation of any manual, analog, or compensation (droop or line loss) biasing in the system.

**NOTE:** The total percentage bias that can be applied to the generator system is limited by the Maximum Generator Voltage Output Bias Percentage setpoint configured in the EMCP.

### 7 Troubleshooting

**Section Incomplete.**

- Excitation Module – check status of LEDs
- No voltage output – check Excitation command link, etc.

#### 7.1 EXCITATION CURRENT AND VOLTAGE MONITORING

**Section Incomplete.**

Add detail on using Excitation Command to estimate Excitation Current and Voltage. Also use for trending over time to detect issues.
Appendix A: Excitation Module Connection Diagrams

EM10 – Self-Excitation (SHUNT)
EM10 – Auxiliary Winding (Internal) Excitation (AREP / IE), 4-wire

Caterpillar: Confidential Yellow

IVR Implementation Guide- Rev. 08
EM10 – Permanent Magnet Excitation (PM)
EM15 – Self Excitation (SHUNT)

EM15 Connection Diagram
Self Excitation (SHUNT)

Notes:
1. External fuses required with EM15 module
2. Recommended 250W, 10A fast acting fuses (CAT PIN: 877001 or equivalent)

Caterpillar: Confidential Yellow
EM15 – Auxiliary Winding (Internal) Excitation (AREP / IE), 4-wire

Notes:
(1) External fuses required with EM15 module
(2) Recommended 250V, 10A fast-acting fuses (CAT PIN 687882 or equivalent)
EM15 Connection Diagram
Auxiliary Excitation (AREP), 3-wire

2-way Connector Functions:
<table>
<thead>
<tr>
<th>Terminal</th>
<th>Label</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2-1</td>
<td>F+</td>
<td>Exciter Field Positive Connection</td>
</tr>
<tr>
<td>P2-2</td>
<td>F-</td>
<td>Exciter Field Negative Connection</td>
</tr>
</tbody>
</table>

3-way Connector Functions:
<table>
<thead>
<tr>
<th>Terminal</th>
<th>Label</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3-1</td>
<td>Shield</td>
<td>Excitation Command PWM Shield</td>
</tr>
<tr>
<td>P3-2</td>
<td>CS+</td>
<td>Excitation Command PWM Positive</td>
</tr>
<tr>
<td>P3-3</td>
<td>CS-</td>
<td>Excitation Command PWM Negative</td>
</tr>
</tbody>
</table>

4-way Connector Functions:
<table>
<thead>
<tr>
<th>Terminal</th>
<th>Label</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>P4-1</td>
<td>X2</td>
<td>Power Input (Aux Winding Connection X2, Z1)</td>
</tr>
<tr>
<td>P4-2</td>
<td>Z1</td>
<td>Not Connected</td>
</tr>
<tr>
<td>P4-3</td>
<td>X1</td>
<td>Power Input (Aux Winding Connection X1)</td>
</tr>
<tr>
<td>P4-4</td>
<td>Z2</td>
<td>Power Input (Aux Winding Connection Z2)</td>
</tr>
</tbody>
</table>

Notes:
1. External fuses required with EM15 module
2. Recommend 250V, 10A fast acting fuses (CAT P/N: 6V7802 or equivalent)
EM15 – Permanent Magnet Excitation (PM)