BONITRON

Solutions for AC Drives

Model M3800
Capacitive Regen Controller

Customer Reference Manual

Bonitron, Inc.
Nashville, TN

An industry leader in providing solutions for AC drives.

ABOUT BONITRON

Bonitron designs and manufactures quality industrial electronics that improve the reliability of processes and variable frequency drives worldwide. With products in numerous industries, and an educated and experienced team of engineers, Bonitron has seen thousands of products engineered since 1962 and welcomes custom applications.

With engineering, production, and testing all in the same facility, Bonitron is able to ensure its products are of the utmost quality and ready to be applied to your application.

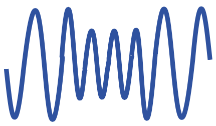
The Bonitron engineering team has the background and expertise necessary to design, develop, and manufacture the quality industrial electronic systems demanded in today's market. A strong academic background supported by continuing education is complemented by many years of hands-on field experience. A clear advantage Bonitron has over many competitors is combined on-site engineering labs and manufacturing facilities, which allows the engineering team to have immediate access to testing and manufacturing. This not only saves time during prototype development, but also is essential to providing only the highest quality products.

The sales and marketing teams work closely with engineering to provide up-to-date information and provide remarkable customer support to make sure you receive the best solution for your application. Thanks to this combination of quality products and superior customer support, Bonitron has products installed in critical applications worldwide.

AC Drive Options

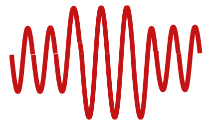
In 1975, Bonitron began working with AC inverter drive specialists at synthetic fiber plants to develop speed control systems that could be interfaced with their plant process computers. Ever since, Bonitron has developed AC drive options that solve application issues associated with modern AC variable frequency drives and aid in reducing drive faults. Below is a sampling of Bonitron's current product offering.

World Class Products



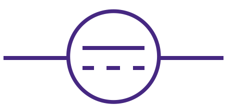
Undervoltage Solutions

Uninterruptible Power for Drives
(DC Bus Ride-Thru)
Voltage Regulators
Chargers and Dischargers
Energy Storage



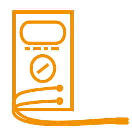
Overvoltage Solutions

Braking Transistors
Braking Resistors
Transistor/Resistor Combo
Line Regeneration
Dynamic Braking for Servo Drives



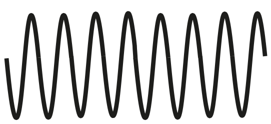
Common Bus Solutions

Single Phase Power Supplies
3-Phase Power Supplies
Common Bus Diodes



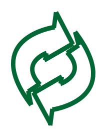
Portable Maintenance Solutions

Capacitor Formers
Capacitor Testers



Power Quality Solutions

12 and 18 Pulse Kits



Green Solutions

Line Regeneration

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1. INTRODUCTION

1.1. WHO SHOULD USE

This manual is intended for use by anyone who is responsible for integrating, installing, maintaining, troubleshooting, or using this equipment with any AC Drive System.

Please keep this manual for future reference.

1.2. PURPOSE AND SCOPE

This manual is a user's guide for the Model M3800 Capacitive Regen Controller. It provides you with the necessary information to successfully install and use the M3800 unit in your application.

In the event of any conflict between this document and any publication and/or documentation related to the application, the latter shall have precedence.

1.3. MANUAL VERSION AND CHANGE RECORD

Revision 00a is the initial release.

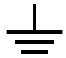
Revision 00b added Section 7.1, capacitor selection notes.

Revision 00c updated Figure 4-2.

Revision 00d updated the setpoints in Section 4.2.

Figure 1-1: M3800 Capacitive Regen Controller

1.4. Symbol Conventions Used in this Manual and on Equipment

	Earth Ground or Protective Earth
	AC Voltage
	DC Voltage
 DANGER!	DANGER: Electrical hazard - Identifies a statement that indicates a shock or electrocution hazard that must be avoided.
 DANGER!	DANGER: Identifies information about practices or circumstances that can lead to personal injury or death, property damage, or economic loss.
 CAUTION!	CAUTION: Identifies information about practices or circumstances that can lead to property damage, or economic loss. Attentions help you identify a potential hazard, avoid a hazard, and recognize the consequences.
 CAUTION!	CAUTION: Heat or burn hazard - Identifies a statement regarding heat production or a burn hazard that should be avoided.

2. PRODUCT DESCRIPTION

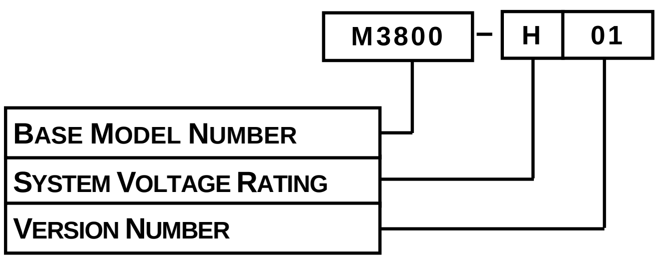
To brake a VFD, the mechanical energy in the system is converted to electrical energy in the DC bus which then must be dissipated or absorbed to prevent the drive from faulting on Overvoltage. There are many methods of managing this extra energy on the DC bus, but the simplest way is to add capacitors to the drive bus; the increased capacitance allows for an increase in energy storage with a smaller rise in voltage. This stored energy from a regen phase can then be sourced back into the drive during a motoring phase. The M3800 Capacitive Regen Controller is designed to monitor and control this external capacitor storage bank.

2.1. RELATED PRODUCTS

- Line Regeneration
  - M3575T Standard Duty Braking Transistor 15A – 600A.
  - M3452 Heavy Duty Braking Transistor 75A – 1600A.

2.2. PART NUMBER BREAKDOWN

Figure 2-1: Example of M3800 Part Number Breakdown



BASE MODEL NUMBER

The Base Model Number for all Capacitive Regen Controller units is **M3800**.

VOLTAGE RATING

A code letter represents the 3-phase AC line input voltage to the module. The voltage rating must be selected for the system voltage that will be applied. See Table 2-1 for available voltage ratings.

Table 2-1: Voltage Ratings

RATING CODE	VOLTAGE
H	230 - 480VAC

VERSION NUMBER

The current available version of the M3800 is **01**.

2.3. GENERAL SPECIFICATIONS

Table 2-2: General Specifications

PARAMETER	SPECIFICATION
System Voltage Range	• 208-480VAC, 50/60Hz
Storage Size	• Unlimited
Control Voltage	• 24VDC, 1A
Inputs	• 2x 24VDC (not currently used)
Outputs	• 4x Solid state relays for system monitoring • 3x 24VDC – 2A for power contactor control
Operating Temp	• 0 to +40°C
Storage Temp	• -20°C to +65°C
Humidity	• Below 90%, non-condensing
Atmosphere	• Free of corrosive gas or conductive dust

2.4. GENERAL PRECAUTIONS AND SAFETY WARNINGS

DANGER!

- HIGH VOLTAGES MAY BE PRESENT!
- NEVER ATTEMPT TO OPERATE THIS PRODUCT WITH THE ACCESS DOORS OR COVERS OPENED!
- NEVER ATTEMPT TO SERVICE THIS PRODUCT WITHOUT FIRST DISCONNECTING POWER TO AND FROM THE UNIT!
- **FAILURE TO HEED THESE WARNINGS MAY RESULT IN SERIOUS BODILY INJURY OR DEATH!**

CAUTION!

- THIS PRODUCT SHOULD BE INSTALLED ON A NON-FLAMMABLE SURFACE WITH CLEARANCES OF AT LEAST TWO INCHES IN ALL DIRECTIONS.
- ALWAYS ALLOW AMPLE TIME FOR THE UNIT TO COOL BEFORE ATTEMPTING SERVICE ON THIS PRODUCT.
- BEFORE ATTEMPTING INSTALLATION OR REMOVAL OF THIS PRODUCT, BE SURE TO REVIEW ALL DRIVE AND/OR RESISTIVE LOAD DOCUMENTATION FOR PERTINENT SAFETY PRECAUTIONS.
- INSTALLATION AND/OR REMOVAL OF THIS PRODUCT SHOULD ONLY BE ACCOMPLISHED BY A QUALIFIED ELECTRICIAN IN ACCORDANCE WITH NATIONAL ELECTRICAL CODE OR EQUIVALENT REGULATIONS.

ANY QUESTIONS AS TO APPLICATION, INSTALLATION OR SERVICE SAFETY SHOULD BE DIRECTED TO THE EQUIPMENT SUPPLIER.

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3. Installation Instructions

CAUTION!

> *Installation and/or removal of this product should only be performed by a qualified electrician in accordance with National Electrical Code or local codes and regulations.*

Proper installation of the M3800 Capacitive Regen Controller should be accomplished following the steps outlined below. Be sure to refer to the AC Drive instruction manual as these steps are performed. Please direct all installation inquiries that may arise during the installation and start-up of this product to the equipment supplier or system integrator.

3.1. Environment

The module should be installed in an area protected from moisture and falling debris. Buildup of dust or debris may cause poor performance and possibly a failure. Operating in a wet environment can pose a shock hazard. The recommended temperature range for operating this module is 0 to +40°C.

3.2. Unpacking

Upon receipt of this product, please verify that the product received matches the product that was ordered and that there is no obvious physical damage to the unit. If the wrong product was received or the product is damaged in any way, please contact the supplier from which the product was purchased.

3.3. Mounting

The M3800 module should only be mounted to a standard DIN rail.

- The unit requires a minimum clearance of two (2) inches in all directions around it when not mounted near a heat source. Heat sources may increase necessary clearances.
- Unit should not be exposed to falling debris or condensation.
- Unit should be installed to minimize wire lengths.

3.4. Control and Customer Wiring Connections

Be sure to review all pertinent AC Drive and system documentation as well as the information listed below before proceeding. Connection points and terminal numbers of the AC drive will be found in the documentation provided with those units.

Table 3-1: Internal Control Wiring

Terminal	Function	Electrical Specifications	Min wire AWG	Max wire AWG	Torque
TB1-1	Control Power (-)	24VDC, 2A	16	14	2.1 lb-in
TB1-2	Control Power (+)				
TB2-1	Precharge Contactor				
TB2-2	Output Contactor				
TB2-3	Discharge Contactor				
TB6-1	Cap Bank POS	0-1000VDC			
TB6-3	Drive Bus POS				
TB6-5	Cap Bank NEG				
TB7-1	AC L1	0-700VAC			
TB7-3	AC L2				
TB7-5	AC L3				

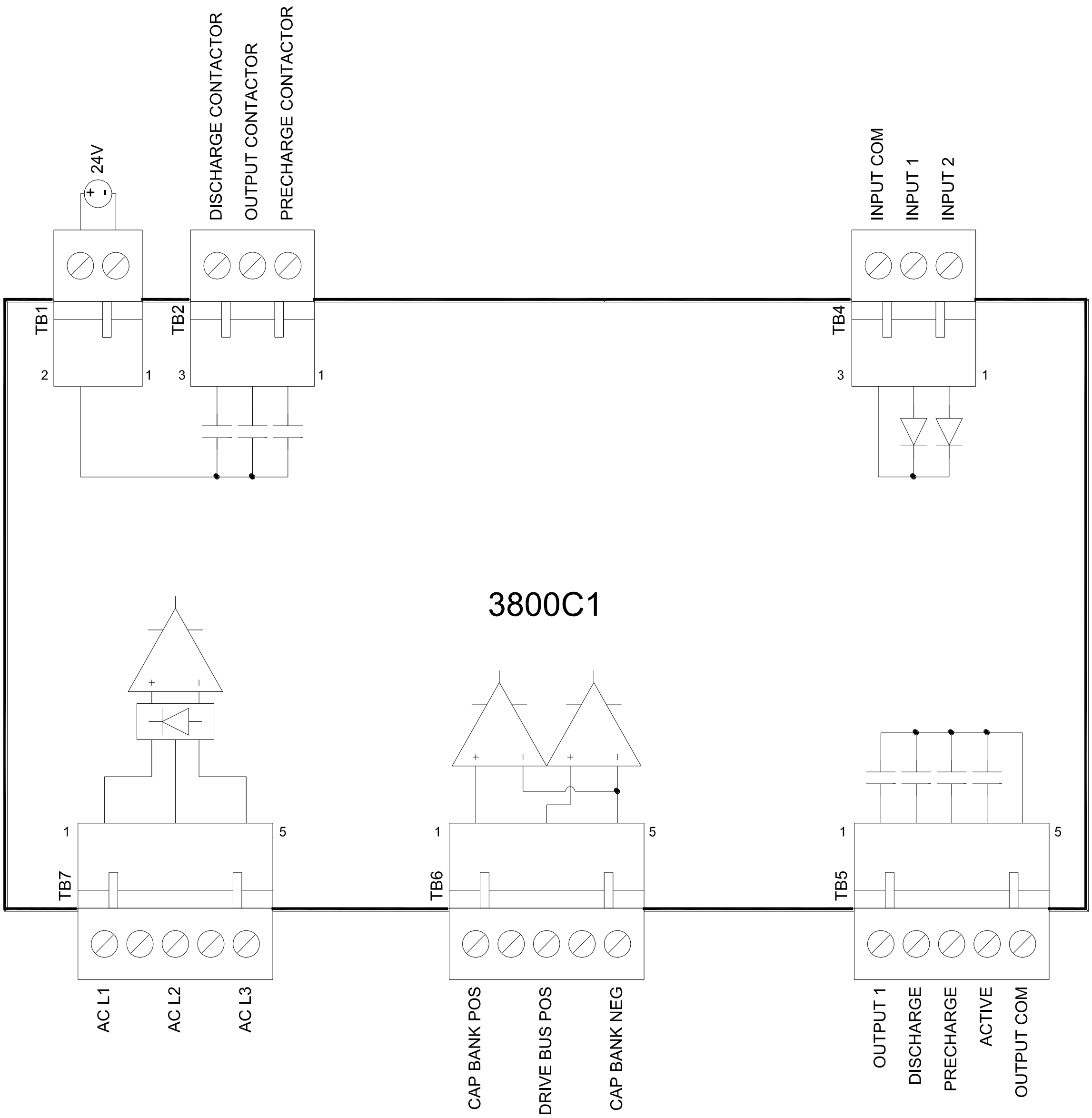
Note: Field wiring for terminals will be copper 75^{O}C wire only.

Table 3-2: External User I/O Wiring

Terminal	Function	Electrical Specifications	Min wire AWG	Max wire AWG	Torque
TB3	Not used at this time				
TB4-1	Input 2	24VDC, 25mA	18	16	2.1 lb-in
TB4-2	Input 1				
TB4-3	Input COM				
TB5-1	Output 1	250VAC, 120mA; 24VDC, 30mA			
TB5-2	Discharge				
TB5-3	Precharge				
TB5-4	Active				
TB5-5	Output COM				

Note: Field wiring for terminals will be copper 75^{O}C wire only.

Figure 3-3: I/O Diagram



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4. OPERATION

4.1. FUNCTIONAL DESCRIPTION

A Capacitive Regen is a simple, passive method for storing regenerated energy from a braking motor; in particular, a Capacitive Regen is well suited for cyclic applications. The M3800, by itself, is just the controller, it must be used in conjunction with a capacitor bank and various external components. It has several voltage feedback points with which to monitor the system, as well as outputs to drive contactors that control the operation of a Capacitive Regen.

4.2. OPERATION

On power up, the controller first checks if the Storage voltage is less than 30VDC; if not, it will wait until the capacitor bank has finished discharging to a safe level. (See Section 4.5 for more info on contactor configuration.)

When it is safe, the M3800 opens the discharge and closes the precharge contactors to begin charging the internal storage bank. As the storage bank is charging, the controller will compare the Storage Voltage to the Drive Bus Voltage to determine when it is safe to close the output contactor.

The condition that must be met to close the output contactor:

$$Drive\ Bus - Storage\ \leq Diff\_Set$$

When this is met, the precharge contactor opens first and then the output contactor closes.

If the storage bank voltage rises above the Overvoltage Setpoint then the output contactor will open until system is reset (power cycle). Alternately, if the Storage Voltage falls below the Undervoltage Setpoint, the output contactor will open and the precharge contactor will close to recharge the storage bank.

4.2.1. SETPOINTS

The M3800 Controller has three (3) adjustable setpoints that control operation. See Table 4-1 for voltage ranges of system voltage setpoints to the corresponding testpoint voltage. See Figure 4-1 for testpoint locations. For example, to set the Overvoltage Setpoint to be 850V, attach a voltmeter from TP16 (COM) to TP8 (OV_Set). Adjust potentiometer R39 until the testpoint voltage is 4.5V. After adjusting the setpoints, you must cycle power to the unit for the changes to take effect.

- **UNDERVOLTAGE**

  This value is the minimum voltage allowed on the internal storage bank before the controller switches back to precharge mode.
  The Undervoltage Setpoint is measured from TP16 (COM) to TP10. This is adjusted with potentiometer R40.

- **OVERVOLTAGE**

  This is the maximum allowable voltage for the storage bank.
  The Overvoltage Setpoint is measured from TP16 (COM) to TP8 (OV_Set). This is adjusted with potentiometer R39.

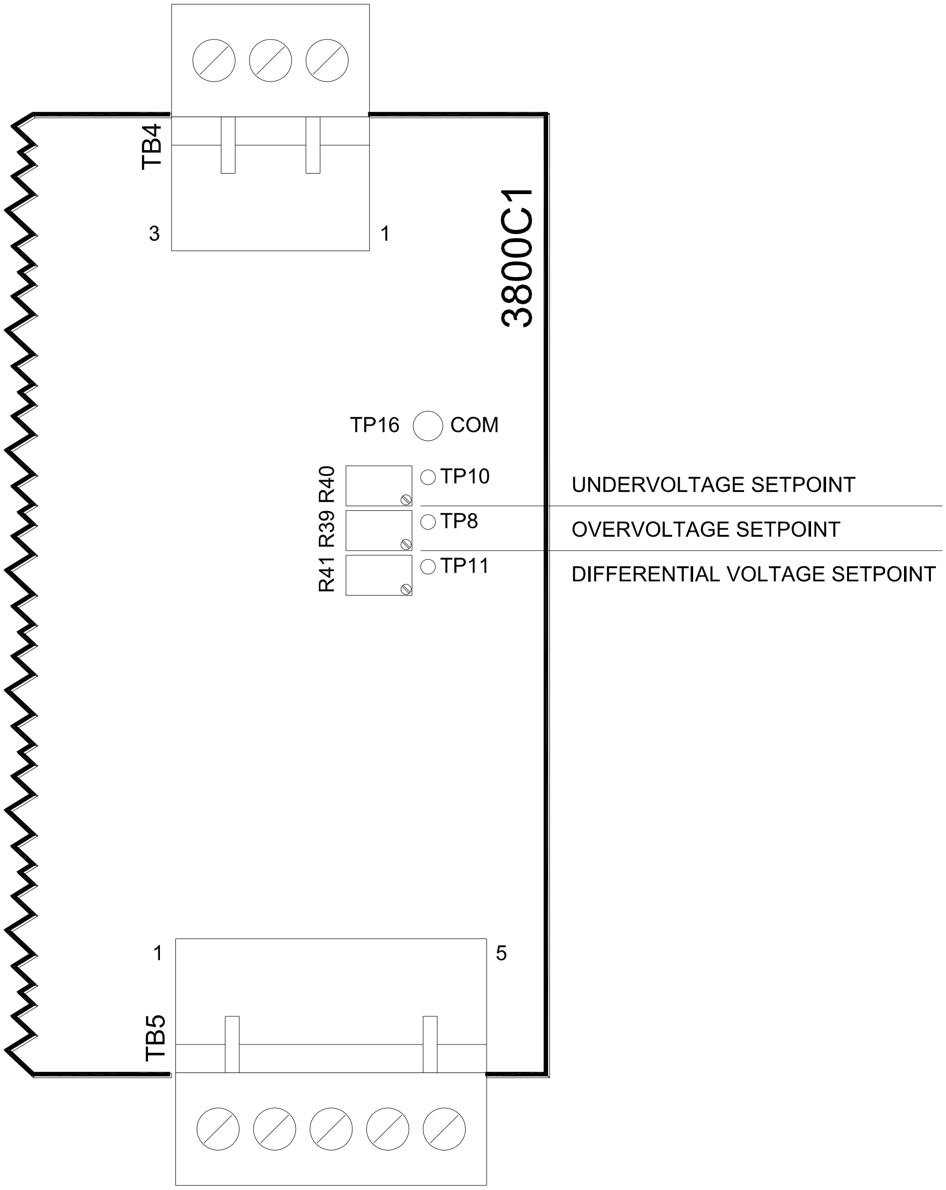
- **DIFFERENTIAL VOLTAGE**

  This defines how close the drive bus voltage must be to the storage bank in order to close the output contactor.
  The Differential Voltage Setpoint is measured from TP16 (COM) to TP11 (Diff_Set). This is adjusted with potentiometer R41.

Table 4-1: Setpoint Ranges

TESTPOINT VOLTAGE	0V	1V	2V	3V	4V	5V
TP10 UV_Set	300V	400V	500V	600V	700V	800V
TP8 OV_Set	400V	500V	600V	700V	800V	900V
TP11 Diff_Set	0V	6V	12V	18V	24V	30V

<u>Figure 4-1: Setpoint Locations</u>



4.3. Internal Control Connections

4.3.1. TB1 – 24V Control Power

This terminal provides +24V to power the M3800 Controller.

- Pin 1 is COM
- Pin 2 is +24V.

4.3.2. TB2 – Contactor Outputs

These outputs are used to drive the three contactors. They must be externally referenced to the same COM as TB1-1.

- Pin 1 drives the Precharge Contactor
- Pin 2 drives the Output Contactor
- Pin 3 drives the Discharge Contactor

4.3.3. TB6 – DC Voltage Feedback

This terminal provides DC voltage feedback from the Storage bank and Drive bus.

- Pin 1 is Storage bank POSITIVE
- Pin 3 is Drive bus POSITIVE
- Pin 5 is Storage bank NEGATIVE

4.3.4. TB7 – AC Voltage Feedback

This terminal provides voltage feedback from the system's 3φ AC line. It is reserved for future expansion and not used at this time.

- Pin 1 is AC L1
- Pin 3 is AC L2
- Pin 5 is AC L3

4.4. User I/O Connections

All the inputs to the unit are 24VDC. They are bidirectional, and can be configured to be sinking or sourcing as the installation requires. It is recommended that inputs be configured as sinking, as this is more failsafe.

The outputs are MOSFET optocouplers, and will show a low resistance (~20Ω) when activated; when not activated, they will appear open.

4.4.1. TB4-1 & TB4-2 – Input 1, 2

These inputs are reserved for future expansion and are not currently used.

4.4.2. TB4-3 - Input COM

All inputs are referenced to this pin.

4.4.3. TB5-1 - Output 1

This output is reserved for future expansion and is not currently used.

4.4.4. TB5-2 - Discharge Status

This status output indicates that the unit is discharging the internal storage bank. If this status contact is closed it means the Discharge contactor is closed and the Precharge and Output contactors are open.

4.4.5. TB5-3 – PRECHARGE STATUS

This status output indicates that the unit is charging the internal storage bank. If this status contact is closed it means the Precharge contactor is closed and the Output and Discharge contactors are open.

4.4.6. TB5-4 – ACTIVE STATUS

This status output indicates that the unit is in run mode. If this status contact is closed it means the Output contactor is closed and the Precharge and Discharge contactors are open.

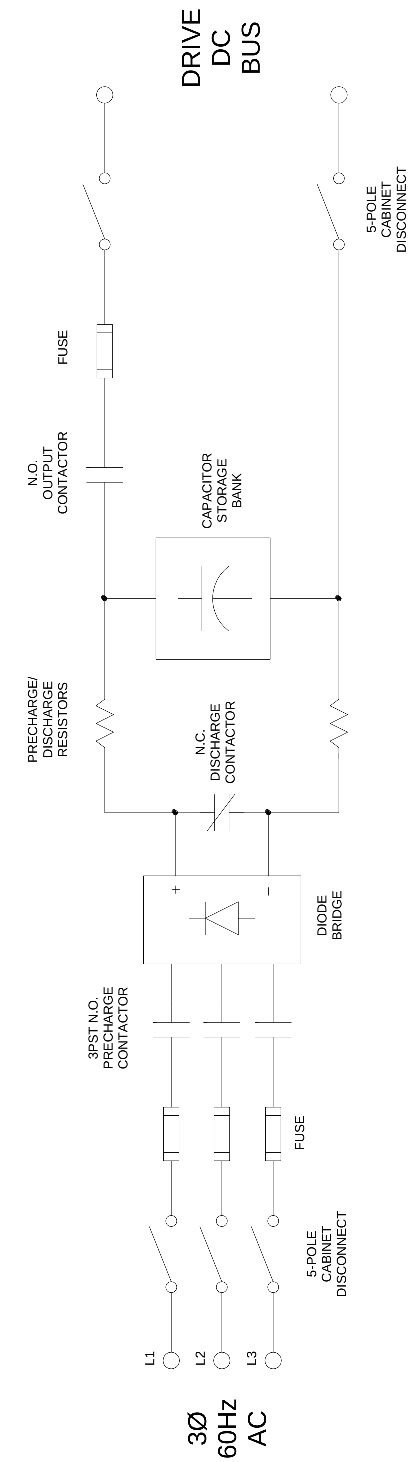
4.4.7. TB5-5 – OUTPUT COM

All status outputs are referenced to this pin.

4.5. SYSTEM LAYOUT

The M3800 Controller, as part of a Capacitive Regen system, requires several external components. Please see Figure 4.2 for a block diagram of the expected system layout.

Figure 4-2: System Layout



4.5.1. STORAGE

The capacitors must be sized according to the voltage and joule requirements of the application; they must be able to absorb the regenerated energy from the drive and keep the voltage below the drive's overvoltage fault level. (See Section 7.1 for sizing example)

4.5.2. PRECHARGE

The M3800 must be able to precharge the storage bank before it can connect to the drive bus; for this, it needs a rectifier and resistor, with a contactor to control them. Because the contactor can be placed in the AC line in front of the rectifier, this contactor can be AC rated only. The necessary current rating of the rectifier and contactor is determined by the resistance value. The resistors should be designed to balance the precharge time with the power dissipated by the resistors: smaller resistance decreases the charge time but increases the wattage requirement. (Sizing example is outlined in Section 7.2)

4.5.3. DISCHARGE

The same resistors can be used to discharge the capacitor bank. There also needs to be a contactor in the discharge path, however this one should be a Normally Closed contactor. This way, if power is removed from the system, it automatically discharges the capacitor bank to a safe voltage. The relay used for discharging must be voltage rated for the system DC voltage, but will not be required to break a voltage above 30VDC. Again, the necessary current rating is dependent on the resistor value.

4.5.4. OUTPUT TO DRIVE

The output contactor must be rated for the max DC bus voltage as well as the max expected regen current.

4.6. USE WITH A BRAKING TRANSISTOR AND RESISTOR

If this system is going to be used in an application where continuous operation is required, you must have a braking transistor and resistor (braking chopper) that is rated for full system braking. There are no extra considerations on the sizing of the braking chopper when used in conjunction with a capacitive regen controller; follow the standard sizing procedure based on the drive system parameters.

Without a braking chopper, there is the possibility that the voltage on the capacitor bank can rise to the drive overvoltage level and cause the system to fault. While this is rarely damaging to the equipment, it will require a system restart.

Adding a braking chopper to the system also allows the drive to begin operation while the storage bank is still charging. If space or cost is of serious consideration, the capacitor bank can be deliberately undersized. Provided the setpoints are properly set, the regenerative capacitor bank will always be storing the most energy possible right before the braking chopper goes active to dissipate braking energy. Thus, the system will still realize some amount of energy savings, and will still be protected from overvoltage faults and nuisance stoppages in cases where the braking load may change.

4.7. STARTUP

This section covers basic checks and procedures that should be used when performing a startup with an M3800 Controller. Before adding a Capacitive Regen, ensure that the drive system works properly.

4.7.1. PRE-POWER CHECKS

- Ensure that the voltage of the AC power system is the same as the Capacitive Regen. It is best if the AC input feed is the same for the Capacitive Regen system and the attached drive.
- Ensure that all connections are tight and that all wiring is of the proper size and rating for operation.
- Verify continuity of all input fuses prior to applying power.
- Check for exposed conductors that may lead to inadvertent contact.
- Check for any debris, shavings, trimmings, etc. that may cause shorts or obstruct ventilation on unit.
- Double check the connection of the DC bus between the Capacitive Regen system and the drive. Reversed polarity can cause catastrophic damage to the drive and the Regen capacitor bank.

4.7.2. STARTUP PROCEDURE AND CHECKS

If possible, monitor the DC voltage across the Regeneration Capacitor Bank while powering on the M3800 controller.

If the Regeneration Capacitor bank voltage is below 30VDC, the Discharge contactor should energize, opening the discharge path. If it is above 30VDC, the Discharge contactor will stay de-energized until the voltage goes below 30VDC.

Once the Discharge Contactor opens, the Precharge contactor will close, and the voltage on the capacitor bank should rise.

Once the capacitor bank charges to a voltage above the precharge voltage setpoint AND the voltage differential between the Regeneration Capacitor Bank and the attached drive DC Bus Voltage is below the Differential Voltage setpoint (See Section 4.2.1), the precharge contactor will open, and the DC Output contactor will close.

If possible, raise the voltage on the DC bus to the Overvoltage Setpoint to ensure the Capacitive Regen Controller will disconnect from the drive bus by opening the output contactor. This can usually be accomplished by running the drive with sustained heavy braking, while the braking transistor and resistor disabled or disconnected.

5. MAINTENANCE AND TROUBLESHOOTING

Repairs or modifications to this equipment are to be performed by Bonitron approved personnel only. Any repair or modification to this equipment by personnel not approved by Bonitron will void any warranty remaining on this unit.

5.1. PERIODIC TESTING AND MAINTENANCE

There are no requirements for periodic testing of these units. It may be beneficial to repeat start-up procedures and checks when performing routine maintenance on other connected equipment.

5.2. TROUBLESHOOTING

CAUTION!

There are no user serviceable parts within the M3800 Capacitive Regen Controller unit. If you are still experiencing problems after you have reviewed this whole Section you may contact Bonitron for additional assistance at (615) 244-2825.

5.2.1. UNIT WILL NOT PRECHARGE

- Check connections to/from the precharge contactor: fuses, disconnects, etc.
- Check Precharge control and status outputs
  - Control: should see 24VDC from TB2-1 to TB1-1
  - Status: should be closed: TB5-3 to TB5-5

5.2.2. UNIT WILL NOT CONNECT TO DRIVE

- Check connections to/from the output contactor: fuses, disconnects, etc.
- Check Output control and status outputs
  - Control: should see 24VDC from TB2-2 to TB1-1
  - Status: should be closed: TB5-4 to TB5-5
- Make sure the capacitor bank is precharging properly.
- Make sure the AC input to the rectifier is the same as the drive AC input, otherwise the voltages may not get close enough to close.
- Check adjustment of the differential set point. (See Section 4.2.1)

5.2.3. DISCHARGE RESISTORS GET HOT DURING NORMAL OPERATION

- Make sure the contactor used in the discharge path is configured for "normally closed" operation. The M3800 Controller requires "normally closed, held open" contacts for proper operation.

5.2.4. UNIT DOES NOT DISCHARGE

DANGER!

Capacitor banks can store significant amounts of energy at lethal voltages. Any voltage above 50VDC should be considered lethal.

Use extreme caution when working with charged capacitor banks.

Use voltage monitoring or measuring devices to determine if the capacitor banks can be handled safely.

- Check all connections to the discharge resistors and that the resistors are within expected resistance.
- Verify the discharge contacts are configured as "normally closed".

5.2.5. DRIVE SYSTEM HAS OVERVOLTAGE FAULTS

- Make sure the capacitor bank is connecting properly to the drive bus. See Section 5.2.3
- If there is more braking energy than can be stored by the capacitor bank, the voltage may rise to the point that the drive system will fault on overvoltage. In order to avoid this, you may need to add a braking chopper to the system. See Section 4.6 for more details
- If you already have a braking transistor and resistor, make sure it is set to operate properly at a level below the overvoltage trip point of the drive.

5.3. TECHNICAL HELP – BEFORE YOU CONTACT US

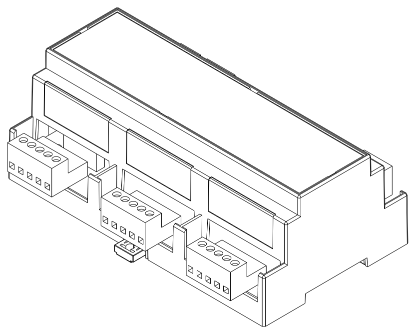
If technical help is required, please have the following information available when contacting Bonitron (615) 244-2825, or email to info@bonitron.com):

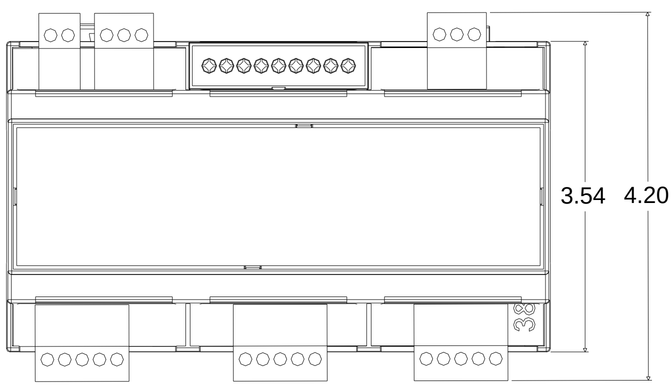
- Model number of unit
- Serial number of unit
- Name of original equipment supplier if available
- Record the Line to Line voltage on all 3 phases
- Record the DC bus voltage immediately after the AC voltage
- Brief description of the application
- Drive and motor hp or kW
- KVA rating of power source
- Source configuration Wye/Delta and grounding

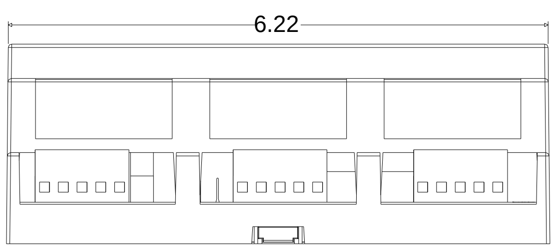
6. ENGINEERING DATA

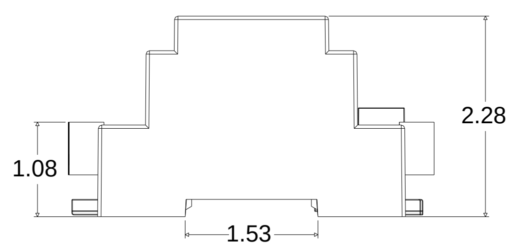
6.1. DIMENSIONS AND MECHANICAL DRAWINGS

Figure 6-1: M3800 Dimensional Outline









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7. APPLICATION NOTE

7.1. SIZING CAPACITOR BANK

The capacitor bank should be sized based on the amount of energy it must store. The amount of energy storage required is determined from the operating parameters of the system. A power profile should be used from the actual process; if that is not available, by estimating using the same techniques as for sizing braking systems. Standard braking transistors and resistors can be used along with a Capacitive Regen, in fact, this is highly recommended to avoid nuisance overvoltage trips when the capacitor bank is precharging or disconnected for other reasons.

7.1.1. PROCEDURE FOR DETERMINING REGEN CAPACITY

1. **Determine Voltage operating range:** (generally from the Nominal DC Bus to the Drive OV trip point).

Table 7-1: Setpoint ranges

NOMINAL AC INPUT	NOMINAL DC BUS VOLTAGE	DRIVE BRAKING VOLTAGE	DRIVE OVERVOLTAGE TRIP LEVEL	CAPACITOR MAX VOLTAGE RATING
230 VAC	325 VDC	375 VDC	400 VDC	450 VDC
460 VAC	650 VDC	750 VDC	810 VDC	900 VDC

If a braking transistor is present, use the Drive Braking Voltage for the V_{high} and the Nominal DC Bus Voltage for the V_{low}.
If your system is not uptime critical and there is no braking transistor present, choose a voltage value for V_{high} that is above the Drive Braking Voltage but below the Drive Overvoltage trip level. The Nominal DC Bus Voltage should be used for V_{low}.

2. **Determine the required energy storage:**
Measure the voltage and current of the system during a typical braking event, multiply together and integrate for time.
You can use standard techniques for sizing braking resistors, the critical value is how many joules per stop are needed.

3. **Calculate how much capacitance you need:**

$$C = \frac{2J}{{V_{high}}^2 - {V_{low}}^2}$$

Example: 1.4kJ storage for a 460VAC system:

$$C = \frac{2(1.4kJ)}{750Vdc^2 - 650Vdc^2} = 20{,}000uF$$

4. **Design a Capacitor Bank:**
Capacitors can be combined in series and/or parallel to achieve the required capacitance and voltage ratings.
For capacitors in parallel, the values add: $C_1 + C_2 + C_3 + C_4 = C_{net}$
For capacitors in series, the inverses add: $\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} = \frac{1}{C_{net}}$
The voltage rating of the capacitor bank must be for the maximum possible voltage that can be seen by the system. Table 7-1 shows

what drive manufacturer's cap bank ratings are given by the Max Capacitor Voltage Rating. Do NOT go lower than that.
For capacitors in series, make sure to use the same value of capacitance and place balancing resistors across each series string. The balancing resistors should be in the range of 40 kΩ, with a power rating of at least 5 W, as they will be continuously energized.

7.2. PRECHARGE CIRCUIT

At power up, the capacitor bank will be completely discharged, and must be brought up to operating voltage at a controlled rate to avoid high inrush currents from the source. The charging currents can be limited by a fixed resistance after an AC to DC rectifier, as shown in the typical system diagram in section 4Section 4.5. Variable frequency drives have precharge circuits integral to their construction, but these circuits should not be used as they are sized to only handle the precharging of the drive's capacitors, and will be severely damaged by the additional capacitance of the regeneration capacitors.
There are three parts to the precharge system: the rectifier, resistors and a contactor.
In order to size the precharge resistor, determine a charging time that is acceptable. This should be on the order of 120 seconds, or two minutes, to allow for reasonably sized components. The equation to calculate this is:

$$R = \frac{-t}{C * \ln\left(1 - \frac{Vc}{Vs}\right)}$$

Where

$$t = Time\ to\ charge$$
$$C = total\ bank\ capacitance$$
$$Vc = target\ charge\ voltage$$
$$Vs = source\ voltage$$

The bank can be considered "charged" if it is within 5% of the source voltage, and the source voltage will be the rectified peak voltage of the incoming line. For a 460VAC system, this will be:

$$Vs = 460Vac * \sqrt{2} = 650Vdc$$

For a resistance example:

$$R = \frac{-120s}{0.02F * \ln\left(1 - \frac{630Vdc}{650Vdc}\right)} = 1720\Omega$$

Now the current for the fusing, rectifier and precharge contactor can be calculated. The maximum current will be the initial current, when the capacitor is completely discharged. In this case:

$$I = \frac{Vs}{R} = \frac{650Vdc}{1720\Omega} = .38A$$

The power rating for the resistor can be determined from the peak power.

$$Ppeak = \frac{Vs^2}{R} = \frac{650Vdc^2}{1720\Omega} = 245W$$

This will not be the continuous rating required, because the charging profile has an exponentially decreasing power. Resistors typically have a peak power rating and a joule rating. The joules required is determined by:

$$Joules = \frac{1}{2}CVs^2 = \frac{1}{2}0.02F * 650Vdc^2 = 4225J$$

If the precharge time is considered to be too long, you can change the time to charge the capacitors and find the new resistance value. Be aware that the peak wattage and currents will increase as well. Likewise, for some large capacitor banks, you may want to use a longer precharge time to allow for more reasonably sized components.

7.3. DISCHARGE RESISTOR SIZING

If the system is configured the way shown in Figure 4-2, then the resistors used for precharging can also be used for discharging. In this case, the capacitor bank will be discharged in the same amount of time that was used to calculate the precharge time.

If there are specific requirements for a discharge time to a safe level, then the time used in the precharging circuit equation should be this discharge time.

NOTES