Greenhouse Electrical Design Considerations

Rev. October 2008

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About this Guide

This document provides background information to help you understand how to use electricity efficiently, safely, and economically. With this understanding, you will be better prepared to work with your greenhouse and electrical equipment suppliers, electricians, local inspection and regulatory agencies, and your greenhouse maintenance staff.

The quality and reliability of electrical power becomes more important as greenhouse mechanization and automation increases. You don't want to risk damaging expensive and hard to service equipment, nor can you afford critical system down time. Proper electrical system design is a critical part of any greenhouse production system.

Specific examples offered here are for general illustrative purposes only. The actual considerations and calculations required for proper engineering are well beyond the scope of this document.

This document is written for readers with a basic knowledge of electrical systems. There are many good references available if you wish to learn more. If you don't have this knowledge, you must consult with someone who does.

Although safety is a primary objective of good electrical system design, the information in this document is not intended as a substitute for any regional or manufacturer's safety guidelines. Always check with your local autoirities before undertaking electrical upgrades and changes.

Introduction

The modern world runs on electricity. It is all around us, supporting every aspect of our daily lives:

- Electricity has evolved from an intellectual novelty less than 200 years ago to the pervasive technology it is today.
- Electrical energy is efficiently produced, transported, and distributed.
- Electricity is easily converted into useful work, light, or heat at the final destination.
- Electrical supply systems are very reliable.
- Electricity is easily controlled.

These attributes make electricity the ideal power source for a very wide range of applications in the world around us.

Well planned and carefully installed electrical systems and equipment can be a pleasure to operate. They will reward you with many years of safe, efficient, and reliable service. On the other hand, poorly planned, badly installed electrical systems can be dangerous, unreliable, and a never ending source of headache and expense!

This document contains information on greenhouse electrical design useful to all greenhouse growers. As a general rule, smaller growers should keep things simple. Increased greenhouse complexity and automation requires a corresponding increase in knowledge and technical support. When reviewing each section, consider your size, needs, and capabilities. Ask yourself if the information provided is appropriate for *your* application.

Where Do You Fit In? Some Grower Profiles:

The scale, scope, and complexity of your operation will help to determine how much you need to understand about electrical matters. For example, if you are a relatively small grower, you may not require complex equipment. On the other hand, even though your needs may be simple, you may be the only one available to manage and maintain the equipment that you do have so some basic knowledge of electrical systems is needed. Larger growers may have much more complex electrical systems, but may also have knowledgeable staff on hand to oversee their proper operation. Regardless of size, every greenhouse operator needs a basic understanding of the engineering and safety considerations of electrical systems for appropriate equipment selection, ongoing maintenance, and troubleshooting.

The Small Grower

A small, seasonal grower may have relatively light electrical loads, with no large motors or other complex equipment. Power supply voltages are usually 240V or less and total amperage for the electrical service is below 200 amps. Single-phase power is often all that is needed. This grower may be more concerned about capital costs than operating efficiency. Standby power generation may not be a critical requirement. A skilled electrician should be capable of designing this relatively simple electrical system.

The Medium Grower

A medium sized, year round grower will require a larger electrical service and three-phase power should be used wherever available. This grower may use larger electrical motors and more complex equipment. Longer wiring distances and larger electrical loads must be accommodated in the overall electrical system design. An integrated standby generator is a requirement for most operations of this size or larger. Electrical system design requires the services of an electrical engineer or an electrician skilled in commercial installations.

The Large Grower

A large commercial grower is more likely to have larger (multi-horsepower) electrical motors, HID lighting or other complex equipment such as boilers or material handling equipment. A three-phase power supply is essential. Long wiring distances may require high voltage primary electrical feeds supplying local step-down transformers and/or more use of higher equipment voltages (480V – 600V) to minimize power distribution losses and reduce wiring size (and cost). Engineering these systems becomes increasingly complex and is more likely to require an overall design prepared by an electrical engineer or an industrial electrical firm specializing in this type of work. Capital savings and ongoing operating cost savings should justify this initial expense, but as always, it is important you select the right designer for your job.

National Electrical Code and Local Code Issues

Let's start with the primary code that regulates all electrical installations and equipment. The **NEC** is your friend! You can develop a safe, cost effective and efficient electrical system by carefully following this electrical code. Electrical system design is complex and the electrical code helps designers and installers select the correct equipment and properly size and arrange wiring and electrical system components. In addition, the **NEC** is generally adopted as the standard by most regulatory agencies in the United States – it's the law!

The **NEC** is updated every couple of years and a code book is published for use by all electricians. This electrical code is well thought out organized and presented. Additional support is available through training materials and explanations published by third parties. All licensed electricians are trained to use the **NEC** or equivalent local codes as their primary guide.

In addition to the National Electrical Code, equipment and component manufacturers often publish very good information that can help you to select and correctly install the best products for your application. This information usually refers to the **NEC** where appropriate, but is often easier to understand because it focuses on the application of just one product.

Most electrical equipment must be installed to local or **NEC** standards under the supervision of a licensed electrical contractor, usually under permit from local authorities. The NEC is the electrician's "bible" but understand that your electrical installation is subject to the scrutiny of "authorities having jurisdiction" who may require specifications beyond the **NEC**. It is the electrical contractor's responsibility to know these requirements and include them in their design.

Equipment Approvals

The **NEC** addresses the design and installation of electrical distribution systems; it does not address individual electrical component design or safety. Independent regulatory agencies such as **UL** and **CSA** establish standards for all electrical equipment and electrical system components, and are responsible for compliance testing and enforcing these standards with all component manufacturers. The **NEC** requires that agency approved components or subsystems be used in electrical systems. *Imported electrical equipment is subject to special inspection if it does not carry these approvals. Your equipment suppliers should take full responsibility for compliance and approvals.*

Electrical System Design

A Good Electrical System Design Must Satisfy Many Objectives:

- Human safety
- Fire protection
- Lightning protection
- Efficient distribution of power
- Reduction of peak loads, particularly where "demand" metering is used.
- Electrical code compliance
- Electrical noise reduction
- Power factor regulation
- Reduced power harmonics
- Possible future expansion
- Maintenance and reliability
- System redundancy for critical systems
- Standby power sources and control
- Last but not least, reasonable capital costs

Clearly, some of these objectives are in conflict with others. It is the job of the system designer to sort through these competing interests and come up with a design that most reasonably satisfies these needs.

Select an Electrical System Designer

Large, complex projects will benefit from the design capabilities of an electrical engineer or experienced electrician with significant greenhouse electrical system design experience. This designer will address your project requirements and resolve most problems before construction begins. The designer will produce a set of drawings and specifications that accurately describe the required electrical system design. While expensive, the costs for this type of design service are typically far less than the cost of future problems and inefficiencies caused by an ad hoc approach to electrical system design.

Get Installation Quotations

Provide copies of these drawings and specifications to several electrical contractors and get competitive bids on an "apples to apples" basis. You can then consider the price, professionalism and competence of each contractor as part of your final selection process. You may omit the competitive bidding process if you are satisfied with the capabilities and competitiveness of one contractor.

When done well, these plans and specifications also become the basis for "as-built" drawings at the completion of the project. *"As-built" drawings will support future maintenance, trouble-shooting and expansion, and are well worth any extra effort and cost.*

Electrical System Installation

Selecting a good electrical contractor

Some greenhouse operations are large enough to justify having their own electrician on staff, but most prefer to work with a good local or regional electrical contractor.

Find an electrical contractor specializing in greenhouse work or a commercial or industrial contractor familiar with the type of equipment found in your greenhouse operation. Check references from similar projects. Many electricians are only familiar with residential or light commercial work and are often not well versed in the specific problems of greenhouses. While inexperienced electricians can always learn about greenhouse equipment as they work, this can increase your costs and increase your risk of mistakes. Even so, the effort might pay off in the long run, as nothing beats having a reliable, local installer with detailed knowledge of your electrical system. This contractor can provide emergency service, perform routine maintenance, or expand your electrical system in the future.

At a minimum, consider bringing in a more experienced electrician or electrical design engineer to help guide you through the most critical aspects of electrical system design and installation.

What can a good electrician do for you?

- Ensure proper engineering of a safe, efficient power distribution system, including electrical service type selection, sizing, and standby generator requirements.
- Provide installation services, including all electrical work, permit applications, and liaison with local authorities and electrical inspectors.
- Commission and test all electrical equipment after the installation is complete.
- Emergency troubleshooting and repairs.

The Design Process

Electrical distribution systems must be designed and sized to match the equipment loads they service. *Always start with your planned site layout and electrical equipment needs, and then work back towards your main power supply.* As you proceed, you must ensure that the upstream components fully support all downstream loads. It is wise to make specific provisions for anticipated future equipment additions, either by incorporating extra capacity into the current distribution system or by providing connection points for future distribution system enhancements.

Work with your greenhouse and equipment suppliers, control systems vendor and electrician (electrical engineer for large projects) to develop the following information:

Load schedule – This is an inventory of all electrical equipment in your project. The total electrical demand of this equipment is used to determine the size and type of electrical service and backup generator required. Group equipment by greenhouse compartment or location to facilitate the following steps:

1. **Main service and branch panel board layout** – This shows the location and size of your electrical service entrance components, your back-up generator and automatic transfer panel, and any additional circuit breaker panels you will need. Consider the location of all connected equipment during this phase as it is often less expensive and more efficient to distribute circuit breaker panels close to electrical load groups, as compared to wiring each piece of equipment back to a central location.

2. **Establish final mounting locations** for each piece of equipment, circuit breaker panel, and other electrical system components. At a minimum, give careful consideration to code requirements for physical access to all equipment and panels. Better yet, locate equipment where you know it will always be easy to access and will enjoy protection from mechanical damage, heat or cold, sprinklers, misters, and other sources of water, dust, and dirt.

3. **Develop "single-line" power diagrams** showing where each piece of equipment will connect to your circuit breaker panels and in turn, where these panels connect to the service entrance and automatic transfer panel. These diagrams are in schematic form and should contain engineering information on the size and number of electrical conductors required for each connection, along with approximate distances between components. This diagram is invaluable during the design and installation quoting phase and can be very useful during future trouble shooting or system expansion.

4. **Develop a wiring and conduit *layout* diagram**. This drawing takes the schematic information from the single-line diagrams and shows the actual location of wiring and conduit runs, the conduit size, and the number and size of wires in each conduit. This diagram is usually developed by the electrical installer and can be very useful during future trouble shooting or system expansion.

5. **Prepare motor control panel, lighting control panel and other electrical interface panel drawings.** These drawings are usually prepared by the respective contractors supplying each of these panels, if your electrician builds these panels on site, make sure he produces these drawings as part of his contract.

6. Prepare ***Control System*** wiring diagrams showing control device locations, control wiring and connection points. These drawings are usually prepared by the controls supplier and are often prepared in conjunction with other power distribution and electrical interface panel drawings.

Efficiency

Electricity costs money – a lot of money over the years. One of the best things you can do for your bottom line is invest in conservatively engineered greenhouse equipment and electrical distribution systems. The resulting energy savings will pay you back year after year. Conservatively designed electrical systems are also safer and much more reliable than systems designed to just squeak by the electrical code minimums.

Here are some points to consider:

- Design your greenhouse mechanical systems and greenhouse equipment to require less electrical energy during operation. For example: consider 'passive' design options such as roof vents for greenhouse ventilation and cooling.
- Bigger is not always better. Do not oversize equipment (beyond your basic operational requirements).
- Heavily used electrical components such as motors, transformers and lights should be the most efficient available for their size or rating. Many motors for example, come in high efficiency versions.
- Where possible, select equipment with high power factor correction values and minimal power distortion (see details later in this document).
- Use heavier gauge wiring to reduce power losses caused by voltage drop.
- Simplify wiring layouts to keep wiring run lengths as short as possible, reducing power losses and initial installation costs.
- Use three phase power and higher supply voltages whenever possible to reduce power losses in wiring and equipment.
- Follow manufacturers' installation recommendations carefully!
- Protect your electrical equipment from heat, cold, and moisture.

Other Engineering Considerations:

Most of us were taught basic electrical theory in school. Unfortunately, most modern electrical equipment chooses to add many complications to these nice simple rules. You don't have to know all the details, but there are a few key issues you need to understand because you will be asked to spend significant amounts of money to properly manage them. *Ignore these issues at your peril.* Wasted energy and unreliable equipment operation can cost you a lot of money.

General Electrical Supply Considerations

Voltage Drop and Power Loss

Even small voltage losses in power supply and distribution wiring can reduce the performance of most electrical equipment and cause overheating and premature failure. Ballasted (HID) lighting and electric motors are very sensitive to under-voltage. Low voltage causes higher current draw, which can cause false or nuisance tripping of your motor overloads or circuit breakers.

Unfortunately, many greenhouses start with marginal power supply voltages at the electrical service entrance. Power companies are required to meet minimum supply voltage standards, but these are significantly lower than the nominal voltage rating. Monitor your supply voltages and ask your power company to raise them if they are low.

You may be stuck with supply voltages that are below nominal ratings, but above legal minimums. The power supply company is not obliged to improve this situation (although there is no harm in asking). Short of installing specialized equipment to improve on-site voltage regulation, your only other choice is to ensure that the rest of your electrical system is engineered to minimize additional voltage drops.

I^2R Power Losses

Wire power losses increase to the *square* of current draw. If you double the current (amperage) in an electrical conductor of fixed size (gauge), you will increase the power loss by *four times*. These power losses hurt you in two ways: higher electrical consumption (cost) and increased voltage drops that may produce faulty equipment operation or premature equipment failure.

Power Factor Correction

An ideal electrical load draws maximum power from the electrical supply when the supply voltage is also at its maximum. If the current and voltage peaks are perfectly aligned, the power factor has a value of 1.0 and electrical energy delivery efficiency is optimal. Unfortunately, most electrical equipment used in greenhouses (motors, lighting ballasts, variable frequency drives) contain inductive or capacitive load elements that shift peak current draw away from the voltage peaks in the clean, sine wave AC power delivered by the power company. This shift increases current draw, resulting in less efficient use of the power generation and distribution system. In effect, the power company must increase the capacity of their generating and power distribution systems to handle the increased current load caused by this shift. Many power companies want you to pay for this inefficiency and will charge you extra if your power factor error exceeds set limits. To add insult to injury, power factor errors cause increased power losses in your own wiring.

A good electrical system designer understands the impact of power factor errors and minimizes the problem through good equipment selection (high power factor options) and power distribution design. If these improvements are not sufficient, you may consider purchasing and installing equipment that corrects power factor errors and brings your overall electrical system into compliance. This is an expensive undertaking and should be considered a last resort.

Harmonics

Some types of greenhouse electrical equipment produce harmonics resulting in significant voltages and currents at multiples of the fundamental 60 Hz power supply frequency. Usually these harmonic currents are small enough to be safely carried by the regular wiring and will be absorbed by other electrical equipment, but occasionally they can become large enough to cause wiring overloads and overheating. This can be a particular problem with ballasted supplementary lighting systems installed on a three-phase power system sharing a common neutral conductor. Again, a competent electrical system designer will be aware of this problem and design your system to safely accommodate this additional current. At a minimum, harmonics represent wasted energy. Select equipment that minimizes harmonic energy.

Electrical noise

Some electrical equipment such as electronic power supplies, battery chargers, variable frequency drives and arc welders contain switching elements that produce high frequency electrical ‘noise’. This noise conducts through the electrical wiring and in some cases radiates through the air, causing electrical interference that disrupts the operation of delicate sensors, computers, radios, TV’s and office equipment. Electrical noise is best controlled at the noise source. Select equipment that contains noise reducing circuitry and follow the manufacturer’s installation and grounding instructions carefully. Unreliable equipment operation can often be traced back to high levels of electrical noise.

Three-Phase Electrical System Considerations:

Phase Reversal

While extremely rare, an accidental reversal of two phases on a three-phase supply can cause major problems. Three-phase motors will run in reverse rotation, potentially causing major mechanical or safety problems.

"Single-Phasing"

Some fault conditions may result in the loss of one of the three phases supplying the motor. This is commonly called "single-phasing". Lightly loaded motors may not trip their standard motor overload protection under these conditions, possibly allowing the motor to overheat to the point of permanent damage. Heavily loaded motors will trip their motor overloads, protecting the motor from damage.

Voltage Imbalance

The same mechanism that causes the motor to overheat in "single-phasing" situations causes problems whenever there is a voltage imbalance between the three phases. Think of single-phasing as an extreme case of voltage imbalance. Small voltage differences of just two or three percent can be sufficient to cause one or two motor windings to overheat and eventually fail. Heavily loaded motors may trip their overload protection circuits, protecting the motor from damage, but depriving you of use the motor until the voltage imbalance is corrected and the protection reset. Your electrical system designer must pay particular attention to this issue and ensure that the electrical load on each of the three phases is close to equal under all operating conditions. This is primarily a problem on electrical systems with mixed single and three phase loads (for example: 120V single-phase / 208V three-phase), where the voltage imbalance is created by a poor electrical system design that does not spread the single-phase loads evenly between the three phases. Consider voltage imbalances as a possible cause if you notice motor overheating or nuisance overload "tripping" not caused by overloading.

Optional Three Phase Protection

You can install phase monitoring equipment that will disconnect power to your critical electrical loads if any of the above failures are detected. This monitoring circuitry can also be configured to start your standby generator for backup operation until the problem is corrected at the source. Phase monitoring equipment is usually installed at the service entrance, but can be installed in front of any critical equipment load. Most greenhouse operators do not install this type of equipment, since the risk of catastrophic damage is relatively low.

Environmental Considerations

Temperature

Greenhouses can get very hot under normal operating conditions and much hotter yet under failure conditions. It is important to understand that most electrical equipment is rated to operate over a specified temperature range and equipment must be de-rated or even shut down if temperature ratings are exceeded. Regardless of absolute temperature limits, reliability and equipment life decline significantly as average operating temperatures rise. *An oft-quoted rule of thumb states that for each 10 degree C rise in temperature, operating life is cut in half.*

Most motors and associated breakers, overloads, and control relays are rated for a maximum ambient temperature of 40 degrees C (just over 100 degrees F) and must be de-rated if operated at higher temperatures. This temperature limit is high, but remember, these components might be living inside an electrical box baking in the hot sun in a greenhouse that is already close to the limit. Combine this condition with the fact that summer 'brown-outs' are a common problem. Low supply voltage causes higher motor current draw, moving closer to the motor overload trip point.

Do not overload electric motors! Conservative motor sizing will provide sufficient reserve capacity to allow operation under the worst combination of high temperatures and low input voltage.

Mount electrical components in the shade in the coolest place possible in your greenhouse. You will be rewarded with much longer equipment life and greater reliability. Direct ventilation can be added to cool your electrical boxes, but this is not a good idea in most greenhouses because ventilation increases the risk of water, dust, and vermin entry, increasing the potential for damage.

Condensation and Water Damage

Water and electricity don't mix. The result is dangerous and your equipment will quickly degrade and fail. You should specify waterproof (NEMA 3 or 4) enclosures for all electrical equipment mounted in greenhouses. Specify NEMA 4X (both water proof and corrosion resistant) for use where frequent exposure to water is a probability. Non waterproof enclosures may be acceptable if additional protection is provided.

Fertilizer solutions are much more corrosive and conductive than clear water. Standing pools of fertilizer solution near electrical equipment can pose an electrical shock hazard. Where possible, avoid locating electrical equipment where it will be in contact with irrigation water or fertilizer solutions. Use extreme caution and disconnect the electrical supply before accessing electrical equipment in these areas. **Ground Fault Circuit Interrupters** (GFCIs) should be installed on electrical circuits installed in wet locations to protect greenhouse workers from shock hazards.

You may still suffer from water damage and corrosion problems even if you use waterproof enclosures, equipment and conduit. Barometric pressure changes will force warm, humid greenhouse air into the electrical system where the excess moisture may condense (water-proof is not vapor proof). A water-proof enclosure will retain this condensate and may in fact 'drown' critical electrical components after a few hundred condensing cycles if this condensate cannot find an escape path. Provide small drain holes at low points to prevent water build-up inside panels and electrical equipment.

Remember this important fact: *Water runs down hill.* Assume water will always find a way into your equipment through leaks or condensation, no matter how hard you work to keep it out. Use water-proofing and sealing materials but don't rely on them exclusively. Make sure water can go somewhere (down) without passing over the most expensive and difficult to replace electrical component. For this reason, *it is good practice to never bring wiring into the top of any enclosure*. Use side entry with drip loops in the wiring or conduit to eliminate water before it can enter the enclosure, or use **bottom entry** (always the best).

Do not put electrical enclosures against the outer walls of a greenhouse where part of the enclosure may be cooled below the greenhouse air dew point. Condensation (inside and outside the enclosure) can cause corrosion and electrical component damage. If you must put equipment against outside walls, install thermal insulation against the wall to thermally isolate the enclosure. Leave a space between the insulation and the enclosure to allow convective air flow for normal cooling.

Solar Radiation and Weather Protection

For electrical purposes, greenhouses should be considered outdoor environments (not protected). All wiring should follow the electrical code standards and must be approved for outdoor use if not protected by a wiring conduit. In particular, the outer jacket of exposed wires should be water proof and have approved Ultraviolet (UV) light protection.

Lightning Protection and Grounding Systems

Contrary to the popular saying, lightning will often strike in the *same* place. Nearby cloud-to-cloud or cloud-to-ground lightning strikes can cause a lot of damage to electrical systems and equipment, start fires, and injure or kill people. If your greenhouse site has a history of lightning strikes, it is reasonable to assume more strikes are in your future. Lightning damage severity can vary greatly over even short distances. Ground elevation, trees, structures, water table, water salinity and soil structure can all affect lightning behavior. Usually your choice of site location is dictated by other factors, so you must deal with the situation as you find it.

Unlike most conventional buildings, greenhouses do not provide very good lightning protection. Direct strikes can couple into greenhouse framing and exposed wiring runs, causing massive damage. Nearby cloud-to-cloud or cloud-to-ground strikes can couple power surges into the long wiring runs often found in greenhouses. These surges travel through the wires, damaging connected equipment or endangering human life.

Lightning Protection Follows Two Broad Strategies:

Limit exposure to direct lightning strikes by diverting energy into the earth *before* it reaches the voltages required to initiate a lightning strike. This strategy also diverts lightning energy away from your wiring and equipment in the event a strike does occur. Lightning protection systems for buildings (lightning arrestors or lightning rods) follow this strategy. Grounding systems provided with lightning arrestors must be installed separately from the electrical grounding system to prevent injection of lightning energy into the electrical system. *Do not connect the two grounding systems*.

Place **protective barriers** at strategic locations in the wiring system to divert induced or coupled energy surges from the electrical wiring into the electrical grounding system *before* they can cause equipment damage or endanger life. This second approach cannot handle the full energy of a direct strike, but can greatly reduce the damaging effects of coupled energy induced by nearby strikes. Surge protection equipment is installed at power or telephone connections, individual electrical outlets, or built into equipment.

The best protection involves a well engineered combination of both strategies. In high risk areas, you may want to consult local experts for full-site lighting protection. At a minimum, install surge protection to protect all critical equipment in your operation and ensure good electrical system grounds.

The NEC has many rules covering the proper grounding of electrical equipment and bonding of the greenhouse power supply neutral to the earth. Specialized equipment such as telephone systems and computer control systems come with a variety of protection devices designed to limit energy and voltage surges and pass this energy harmlessly to earth. You should also purchase good quality surge protection devices to help protect a variety of plug-in equipment like PCs, telephones, TV’s, photocopiers and the like.

Basic protection can always be improved with the addition of higher quality and properly grounded protective equipment. No solution is perfect, but risk can be greatly reduced.

These protection systems will not work unless they are connected to a good earth grounding system!

Electrical System Grounding

Good electrical system grounding is an essential part of all lighting protection systems.

The electrical grounding system is arguably the most important part of your electrical system and the least understood or appreciated. This one system is your primary protection against a wide range of failure modes. Lightning protection, equipment and wiring protection, fire prevention and human safety all depend on a good earth ground.

At a minimum, ensure your electrical system has been installed with a good grounding system installed according to Code. You should also have your grounding system checked every few years to confirm it is still performing properly. Out of sight may be out of mind, but not when it comes to safety.

Good grounding systems don't stop working when the lightning storm passes. They continue to provide a safe return path for dangerous electrical currents caused by faulty wiring or equipment. Diversion of this energy to earth prevents fires, equipment damage and personal injury. Safety protection devices such as fuses, circuit breakers, GFCIs or motor overloads will trip if the electrical fault current exceeds their settings, blocking electrical flow until you find and correct the original fault and reset the protection device.

Standby Generators

Most greenhouse operations cannot survive for very long without electricity. As little as an hour without ventilation in summer or heat in winter can lead to catastrophic crop loss and possibly even greenhouse equipment damage from heat or freezing. This type of damage will only occur during weather extremes, but this is precisely when the electrical power supply is least reliable.

Consider:

- The ice storm that brings down the power lines and then freezes your crop shortly after the power fails.
- The heat wave that causes distribution grid overloads and black-puts and then cooks your crop shortly after the power fails

Stand-by generators are essential in most greenhouse operations. If you cannot afford a generator now, you should at least design your electrical system to accept one as soon as you can afford it.

Automatic Starting and Transfer Panels

A standby generator that is not running during a power failure is not much use to you. Consider installing a reliable automatic transfer panel to automatically start the generator and transfer the connected electrical loads, even when there is no one present. *Transfer panels must be designed and installed in accordance with the NEC rules – The power company lineman out fixing your power connection does not want to be electrocuted when you fire up your generator.*

You have several considerations when selecting and sizing a back-up generator and transfer panel:

1. Make sure all critical electrical loads are compatible with the generator output voltage and phasing.
2. Size your generator to run all critical loads that might run at one time. For example; you may need to either heat or cool your greenhouse during a power failure, but probably not both at once. Size the generator for the larger of these two loads (with some additional reserve) and make sure both loads cannot run at the same time. The generator must also be able to provide the peak starting current required by your electric motor loads.
3. Locate the standby generator as close as possible to the utility power connection point to reduce wiring power loss and voltage drop.
4. Connect all emergency electrical loads to power circuits fed from the standby power transfer panel and all non-emergency loads to circuits fed directly from the main electrical service.
5. Use the power management functions of your computer control system (if available) to lock out all non-critical equipment during backup power operation, reducing peak generator loads.
6. Use your computer control system to stagger electric motor starting times, further reducing the excess motor starting capacity requirement.
7. Make sure your generator is reliable, properly adjusted (voltage and frequency control), well maintained and has a good supply of clean fresh fuel. Some greenhouse operators install dual fuel systems to give them more options during prolonged power outages.
8. Regularly test the generator system under load.
9. Make sure you have someone available with a good understanding of your generator operation and electrical load management when the generator is running. *You will need to manage the generator very carefully during prolonged power outages, since you are already on your backup and likely have no other reasonable options should it also fail.*

Powering Safety Equipment

Greenhouses are buildings with generally low human occupancy rates. Even so, you may be faced with fire regulations or insurance requirements designed to increase human safety and reduce financial risk. Requirements may include safety lighting, alarm systems or provisions for emergency operation of some equipment. Wiring and power supply to these systems is a critical component – if the fire damages your power supply or connecting wiring, you will no longer have power available to operate safety equipment or mitigate potential damage.

Carefully Follow Installation, Maintenance And Testing Procedures As Dictated By The Safety Agencies.

Equipment Sizing and Selection

Electric Motors, Overload and Service Factor

Electric motors are rated in horsepower or kilowatts and often have a specified current draw, stated in amps, *at the stated input voltage*. The NEC allows motors to be operated with some current overload to ensure continued operation as the equipment ages, even when faced with lower utility supply voltages or elevated operating temperatures. This allowable overload Service Factor (S.F.) ranges from 115% to as much as 140% of the motor name plate current draw. *Do not use this extra motor capacity under normal operating conditions*. If you need a bigger motor for normal operating conditions, buy a bigger motor – they don't cost much more and they will run cooler and give you much greater reliability and longevity.

An important part of any electrical installation is an amperage test of each piece of equipment under normal operating load to confirm proper sizing of the motor and to determine the correct settings for the motor overload protection.

Circuit Breakers and fuses

Circuit breakers and fuses are designed to protect your *power distribution system* from excessive current draw that could damage wiring or start a fire. *They do not protect the connected equipment.* Circuit breakers and fuses must match the wire conductor capacity, which in turn must be capable of supporting downstream loads. Never fix a circuit tripping problem by installing a larger-than-recommended breaker or fuse. Find the underlying problem and correct it.

Manual Motor Starters

These devices take the place of circuit breakers and contain additional protective circuitry to protect the motor from excessive current draw. These protective devices must be carefully sized and set to match the motor current draw and Service Factor inscribed on the motor name plate. Overloaded motors will cause these protective devices to trip before the motor is damaged. Often this is viewed as a 'nuisance' and operators increase the overload current settings or select a larger MMS size to eliminate these 'nuisance' trips. *This is a mistake!* It is also against electrical code rules. Find and correct the underlying problem or your motors will suffer short service lives and require frequent replacement.

Motor Overloads

Motor overloads may be built into the motor (thermal overloads) or may be installed externally in the motor supply wiring. They provide the same motor protection as manual motor starters but are designed to work *with* circuit breakers or fuses, rather than *replace* them. As with circuit breakers and motor starters, frequent tripping of motor overloads is an indication of a problem that requires further investigation.

Ground Fault Circuit Interrupters

GFCIs are designed to protect people from potentially dangerous stray currents. These protective devices disconnect the power when they detect small current imbalances in the power wires, indicating leakage currents from faulty circuitry or equipment into ground. Install GFCIs wherever there is a possibility of a person's body accidentally making a connection between electrical equipment and ground. Typically, convenience receptacles are protected in this fashion, but other equipment may also benefit from this form of protection, particularly where risk of human contact is high. Your electrician, the NEC and local authorities will all have opinions you should (must) consider.

Electric Motor Speed Controls

Many greenhouse equipment applications can benefit from motor speed control.

Standard AC electric motor speeds (RPM) are fixed by the motor design and the operating frequency (60 Hz). Some inexpensive motor designs slow down with increasing mechanical load, but this 'feature' is not controllable and usually detrimental. Some types of motors are designed to operate at several different fixed speeds. These motors are typically more expensive than single-speed motors, often cost more to install and control, and are typically used in highly specialized applications such as ceiling fans.

Speed Control issues:

Energy savings are not directly related to motor speed. Electric motors don't 'produce' the horsepower or consume the electrical power shown on their name plate. Motors are capable of producing *up to* their name plate ratings in continuous operation, but in fact will only match their actual mechanical loading. A free wheeling electric motor running at full speed will likely be cool to the touch and use much less electricity than a fully loaded motor. It is also doing no useful work. The small amount of electricity it uses goes entirely to waste, so the true operating 'efficiency' is 0%. The amount of work (and electrical load) is always defined by the equipment driven by the motor. Changing the equipment speed will change the mechanical loading and consequent electrical load. It is usually possible to save electrical energy by running equipment at lower speeds, but there are often limits to what is practical.

Consider an application that requires a reduced flow rate under some operating conditions. This looks an opportunity for a speed controlled motor, but it may not be that simple:

> Many motor applications (pumps, fans) require a specific rotational speed to achieve the required outlet pressure and volume or flow. By design, these requirements are often at, or very close to the full speed of the motor, assuming the equipment was properly sized for the application in the first place.

In rough terms, if you reduce the speed of an optimally sized centrifugal pump by 25%, the pumped water volume will drop by about 25%, as expected. Assuming similar pump efficiency at both speeds, the electrical consumption may drop to perhaps 50%. This is good. Unfortunately, the discharge *pressure* will also drop substantially, possibly below the minimum pressure requirements of your application. If this is the case, you will have to run the pump at a higher speed in order to maintain sufficient pressure (with a reduction in energy savings), or you might want to consider the following alternative:

A pump operating at full speed, but with restricted flow will consume less energy than the same pump operating at its design flow rate. Outlet pressure will increase slightly, so it is no longer a limiting factor. This solution might be the better alternative for many applications because it is simple and less expensive while still saving some electricity and preserving sufficient outlet pressure to meet the application requirements.

Before you can decide on the best plan of action you need to have a thorough understanding of:

- The pressure and flow requirements of your application
- The output dynamics of the controlled equipment over the full range of speed adjustment.

Many greenhouse systems can be engineered to work around speed control limitations to some degree, but in the end there are usually minimum pressure or volume requirements that prevent much usable speed turndown. Greenhouse growers are often overly optimistic when considering the control and energy saving benefits of motor speed controls.

Often, staging several single speed fans or pumps can deliver most of the benefits of speed control with few of the limitations. As a bonus, staged equipment provides some on-line redundancy as compared to a single speed-controlled motor. High end computerized greenhouse control systems have built-in control strategies that produce good proportional control using either staged single speed equipment or variable speed equipment.

Speed control *is* very useful where you cannot easily match the standard motor speeds to your application requirements. For example, it is much more electrically efficient to use larger, slow turning fans for Horizontal Air Flow applications, but you may only be able to achieve these (low) speeds by using a speed controller compatible with the fan motors. Not only is it more efficient electrically, but you will improve crop uniformity by reducing local 'dry spots' that are often caused by the strong air movement. Slow moving fans are also much quieter – a real plus in retail or high occupancy greenhouses. Often the speed is never varied once the optimal speed is determined.

Variable Frequency Drives (VFD)

There are several types of variable speed motor controls available. All add cost and complexity to your system. The most common type of electric motor speed control is the Variable Frequency Drive. VFDs allow you to control the operational speed of compatible electric motors by varying the frequency and sometimes the voltage of the motor power supply. Operating frequency may vary from just a few Hz up to as high as 180 Hz (three times normal speed) *when used with appropriately sized and rated electric motors and associated mechanical systems*. As a side benefit, many VFDs offer a number of other useful functions such as soft starting and speed ramping, motor overload protection and motor rotation reversing. Sometimes these peripheral functions alone are sufficient justification to install VFDs, but usually the speed control function is the primary reason, allowing you to precisely match motor speed to load requirements for improved equipment control and reduced energy costs.

VFDs are coming down in price and are often marketed as "fantastic opportunities for huge energy savings". These claims are often, but not always, true. While VFDs may be of great benefit in many applications, consider the following points:

- VFDs and associated optional reactors and filters consume power for their own operation. This wasted power can be 5% to 10% of the total electric motor power consumption, so if you run a motor at 100% of name-plate speed on a VFD, *you are actually using up to10% more energy than if you directly connected the motor to your electrical supply.* Energy savings will be significant only if you can operate the motor at reduced speeds for long periods of time.
- Modern VFDs are smaller, more efficient and less expensive than earlier generations, but they still produce high frequency electrical noise and voltage spikes. This noise can interfere with other electrical or electronic equipment or sensors. *Proper installation is imperative to reduce this interference and maintain safety!*
- Some VFDs generate audible noise that can interfere with nearby human activities. The fundamental operating frequency of most VFDs can be changed to reduce or eliminate this noise, but this may also reduce drive efficiency. Mount VFDs where noise won't bother people.
- VFDs have fairly large inrush currents when first powered. This peak in-rush should be considered when designing power distribution and standby generator systems.
- VFDs are expensive and often require additional expensive wiring and filtering components to operate properly and reduce interference problems with sensors and other electronic equipment.
- Not all electric motors can handle the power harmonics and voltage spikes produced in VFD controlled motor circuits. Electric motors must be rated for use with VFDs. Not all are. Older motors and power connection wiring may need to be replaced. Expensive load reactors may be required to protect the existing equipment if upgrades or replacement are not practical.
- The interconnect wiring between the motor and the VFD must meet the line balance and grounding requirements of the VFD. Special cabling is available for this purpose. In most installations it is best to mount the VFD close to the motor(s) it controls. Local mounting will improve safety and reliability while reducing electrical noise and the amount of expensive interconnect wiring.
- VFDs should be mounted in cool, clean, dry locations.
- VFDs produce a lot of waste heat that must be rejected to the surrounding environment. You must give a lot of attention to their cooling requirements. You cannot pack VFDs into an electrical enclosure and expect them to work. VFD manufacturers solve thermal problems by creating open pathways for cooling air to flow through the VFD units. Larger units sometimes used fan cooling to supplement convective air flow across the integrated heat exchanger. If these pathways become clogged with dust and dirt, or if water splashes onto these units, they will fail. Sealed VFD units designed for wet, dirty environments are available but are much more expensive.
- VFDs are complex. Your electrical system designers and installers must make many correct decisions and must follow installation, programming and testing procedures exactly. Complexity increases the risk of failure, and makes future servicing more difficult.

Variable Speed DC Motors

Solid state speed control of DC motors in specialty applications such as conveyor systems, blowers and fans is becoming more common. These are often integrated systems (DC power supply, speed control and motor form a single unit), making installation somewhat easier.

Just as with VFD's, the cost and complexity of these motors is high. The benefits of accurate speed control, good electrical efficiency and supporting features make these motors good candidates for many specialty or high use applications. Carefully consult the documentation and installation manuals provided by the manufacturer for specific information.

Reversing Motors

Reversing motors are used for many greenhouse applications including shading systems and roof or wall vents. These motors, along with associated gear boxes and shafting, are used to position the controlled equipment to produce the desired greenhouse environment. In most situations the control system is able to achieve reasonably accurate positioning by simply keeping track of the elapsed opening and closing times (assuming a fixed motor speed). These calculated positions are automatically recalibrated each time the equipment drives to one of the travel limits. In situations where very accurate positioning is required, or where motor speed (and thus position) is un-predictable, a separate position sensor must be installed. The control system uses position information from this sensor to correct calculated position errors. Many gear motor systems can be supplied with a potentiometer option to directly measure position and send a corresponding signal to the control system.

Operating and Master Travel Limits

Most greenhouse reversing motor applications require switch-based logic ('operating' travel limits) to stop the motor at the mechanical travel limits of the controlled equipment (fully open or closed roof vent). These switches may be an integral part of the motor-gearbox assembly or they may be mounted externally on the controlled equipment.

In addition, some reversing motor applications require additional independent switch logic ('safety' or 'master' travel limits') to shutdown the motor if the mechanical operating travel limits fail. Safety limits are a requirement if consequential equipment damage is possible. When safety limits are engaged, the underlying failure must be resolved before the equipment can be placed back into automatic operation. These switches may be an integral part of the motor-gearbox assembly or they may be mounted externally on the controlled equipment.

Both operating and safety limits must be properly installed and adjusted so they can detect travel and safely shut down the motor before mechanical damage can occur. Operating limits must be set so they stop the motor before the equipment travel reaches the safety limits.

Reversing Motor Types

Three Phase

Three phase reversing motors are simple and come in a wide range of sizes. They will always reverse rotation properly when any two electrical phases are “swapped”. Three phase motors can operate continuously, thus not placing any limits on the control system. Three phase motors are recommended for larger reversing motor applications whenever available.

Single Phase

Two-winding, ‘instant’ reversing, single-phase motors have a separate electrical winding for each rotational direction. These motors are controlled by energizing the winding for the desired rotation direction and de-energizing the other winding. This design is well suited to smaller mechanical loads and most ‘tube’ motors and small gearbox based units use this type of motor. In some situations, these motors have intermittent duty cycles and must be given sufficient ‘off’ time to allow the motor windings to cool between operations. Mechanically overloaded motors will have shorter duty cycles and shorter working lives. Usually the automatic control system provides sufficient off time between operations to satisfy the duty cycle requirements, but this may be defeated when the motor is run manually. Make sure the motor has built-in thermal protection.

Other single phase motors rely on reversal of the ‘*start’* winding polarity to start the motor in the desired rotation. Once running, a separate ‘*run’* winding will keep the motor running in whichever direction it was started. *It is imperative that this type of motor be fully stopped before a direction change is attempted or the motor will just continue to run in the same (now wrong!) direction.* This can be disastrous as the mechanical operating travel limits only operate properly when the motor is running in the expected direction. Expensive time delays must be installed in the control wiring to provide a few seconds of delay to ensure the motor comes to a complete stop before the motor can be started in the reverse direction. Master safety travel limits must also be installed to shut down operation if the motor ever does end up running in the wrong direction.

Greenhouse Lighting Considerations

Supplementary lighting systems use very large amounts of electrical energy. Most lighting fixtures are very sensitive to even small drops in supply voltage. Efficient, reliable operation requires a well designed electrical distribution system. Your lighting fixture supplier is a good source of information for this specialized electrical design.

Layout

- Determine the quantity of light required to supplement your crop during the seasonal low light periods.
- Observe and record potential detrimental obstructions for a uniform light layout.(Such as heating pipes or ducting)
- Request a light plan from a reputable greenhouse lighting manufacturer for optimal layout and spacing considerations. – Ask questions if you are unclear during any point of the consultation process.
- Calculate the total lighting electrical load.
- Consult an electrical contractor to determine available electrical supply.

Design Considerations

- Energy efficiency (light output per watt) is affected by ballast efficiency, low voltage drop wiring, lamp type and age and reflector and lamp cleanliness.
- Less than 2% voltage drop is optimal for core coil and mandatory for reactor style ballasts.
- The stability of the voltage in your area is extremely important. This can impact the style of ballast offered for your installation and the success of the project.
- Line to Line installations offer the advantage of removing the 3^{rd} harmonic (improved efficiency) and reducing the number of electrical conductors required in certain applications.
- Lighting loads act as a heat source, providing some offset for fuel costs.

Maintenance of Fixtures

- Clean your bulbs and reflectors annually for increased efficiency.
- Bulbs should be tested after 10,000 hrs of operation for lumen maintenance (every 1000 hours equates to 1% lumen depreciation where power consumption remains constant while output diminishes over the life of the bulb). Replace the bulbs when the light output deficit is sufficient to justify replacement on energy savings alone.
- Reflectors should be tested after 5 seasons for output efficiency.
- Consider any restart delay time requirements of the fixtures. HID lights often need a ‘cool down’ period before restarting. This may need to be addressed internally within the fixtures or externally by the lighting control system.

- Minimize “short-cycling” of ballasted lights. Short-cycling will shorten lamp life and reduce light output.
- Older, poorly maintained crop lighting systems silently ‘steal’ your electricity. Good maintenance is a critical part of crop lighting.

Conclusion

Electrical system design, installation and operation are a complicated business. The modern greenhouse depends on the reliable and efficient operation of many electrically powered systems. Be very careful when considering low cost, minimal solutions for your electrical system. Usually, money saved up front is quickly wasted in the daily operation and maintenance of your electrical system. Worse yet, an unreliable system can cost you your crop. Don’t cut corners.

Make sure you have access to qualified people to assist you with all aspects of your electrical system. Your equipment suppliers should be able to provide you with good advice to help you complete a safe, reliable and efficient installation of their products. Your electrical engineer or electrician should be able to pull it all together to give you a solid, integrated power distribution system. Your maintenance staff should have a good understanding of the equipment they work on and be qualified to do that work.