Transfer Equipment Controls

Control Types

The type of control system for the transfer switch will vary depending on the type of switching equipment it is. A manual transfer switch for example, will have no electrical controls where a fully automatic switch may utilize a microprocessor with user programmable features. Most switches utilize a type of control based on either traditional relay functionality, solid–state circuits, or a microprocessor based system.

Earlier designs of control systems were relay based, with solid state controls becoming widespread in later designs. The most recent designs employ microprocessor systems[1]. Any of these controls monitor voltage and frequency of each source and compare those signals to acceptable specification windows for the specific parameters. These specification windows are adjustable or programmable. This comparison is the basis for the control decision to initiate switching to the alternate source. Each type also can include optional functions for metering, display and remote annunciation. More sophisticated microprocessor based control systems can also include additional monitoring functions such as phase rotation detection, loss of phase detection, voltage imbalance, and more. Time delay functions for parameter evaluation, transfer and retransfer control are also often included. Frequently, clocks to time for automatic exercising of a generator set are additional equipment or, in the case of microprocessors, integrated into the control itself.

Transfer switch equipment may be designed with manual, nonautomatic, or automatic operation. The type of control system for the transfer switch will vary depending on the type of switching equipment it is.

Manual Transfer Switches

Manual switches, as the name suggests, are manually controlled and require direct operation by a person to transfer the load. This operation is through a lever or handle; the switch does not have electrically actuated solenoids, contactors, or linear motors. The actual contact mechanisms are operated through the use of spring energy in order to achieve a “quick” make or break of the current carrying contacts. The handle operates the spring mechanism, in effect loading the springs with energy. These switches do not have monitoring capability for the power sources.

Nonautomatic Transfer Switches

Nonautomatic switches, similar to manual switches, are controlled by an outside source which could be an automatic transfer switch. This type of design utilizes electrically operated transfer mechanisms. Transfer of the load with these switches is accomplished with an electrical signal from either an operator or from an external control. As with manual switches there is no source monitoring capability. Often these switches can also be operated manually.

Automatic Transfer Switches

Automatic switches incorporate electrical controls which monitor both power sources and if the connected source becomes unacceptable, will transfer the load to an acceptable source (if available) without operator involvement. In the

1 Contemporary controls available on transfer switches from Cummins Power Generation are solid state, Power Sentry, or microprocessor, “PowerCommand®”.

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Automatic Transfer Switches (cont'd)

case of a backup generator system, the first action, if the primary source becomes unavailable, will be to send a signal to initiate automatic start of the generator set. When the primary source of power returns and is within acceptable parameters, the control will initiate switching back to that source and, in the case of a generator system, initiate the stop sequence of the generator set. Usually an automatic transfer switch can be set to operate in nonautomatic mode or operated manually.

Automatic Control Modes

Utility to Generator

The most common application is where a utility (mains) is the normal of power and the generator set is the emergency standby source. In this application the normal power source is preferred, and the automatic control will always connect the load to the normal source when it is available and acceptable (after standard time delays).

The basic functions of an automatic utility–to–generator set control are the following:

1. Continuously monitors the Normal power source and senses unacceptable power. Acceptable power is defined by the settings of one or more sensors referenced to the nominal system voltage. All automatic controls include undervoltage sensing and optionally may include any or all of the following; overvoltage, over/under frequency, loss of single phase, and voltage imbalance/phase rotation. If power is outside any of the sensor(s) settings, power is unacceptable and the control begins the Start Time Delay.
2. Senses when power remains unacceptable for a predetermined amount of time. At the end of that Start Time Delay the control signals the generator set to start. The control monitors the voltage build up as the generator set accelerates. When the generator voltage reaches the pickup setting of the emergency side undervoltage sensor the Transfer Time Delay begins. The purpose of the Transfer Time Delay is to allow the engine governor to stabilize engine speed before applying load to the generator set. It may also be used in multiple transfer switch installations for step loading the generator set.
3. Transfers the load to the generator set when the Transfer Time Delay is complete. If required, an additional Programmed Transition Delay may be used. This delay may be used, when more than one transfer switch is connected to a generator set, to deliberately offset the timing of multiple load connections, thus reducing transient affects on the generator set.
4. Senses the return of acceptable utility (normal) power source voltage and begins the Retransfer Time Delay, which gives the utility source time to stabilize. Occasionally the return of the utility may be brief, followed by unacceptable conditions, before it returns and stabilizes. The Retransfer Time Delay also provides a minimum run time for the generator set once started. An immediate bypass of the retransfer time delay is automatic should the generator set stop inadvertently during this delay.
5. Retransfers the load to the Normal power source when the Retransfer Time Delay is complete and begins timing the Stop Time Delay. The retransfer function is always between two energized sources, and an additional control

Utility to Generator (cont'd)

function for reducing inrush currents may be required for motors, lightly loaded transformers, UPS and other electronic loads. This delay is a deliberate momentary delay in the neutral position of the switch (i.e. no power sources connected to the load side) for the purpose of allowing voltage decay of inductive loads to avoid transition issues.

6. Sends a stop signal to the generator set after the Stop Time Delay. This delay allows the generator set to cool down while running at no load before being shut down.

Generator to Generator

The generator set–to–generator set automatic control operates two generator sets, one being an alternate source to the other, running at alternate times, to provide power to a load. The basic functions are similar to the utility–to–generator set control, except as follows.

The generator set–to–generator set control may include a programmable Change–Over Clock, which can be programmed to alternately start, run, and connect one generator set for a selected time and then to start, run, and connect the other generator set for a selected time. The Change–Over Clock determines which generator set has priority to run and assume load, when the control is set for automatic operation (Source Selector Switch). Transfer and retransfer are controlled by the change–over clock. In the event of a generator set failure, the control automatically starts the other generator set and transfers the load to the good source.

The Source Selector Switch has three positions; Automatic/Source One/Source Two. In the Auto position, the Change–Over Clock determines which generator set has priority to run and assume load. In the Source One position, the Source One generator set has priority to run and assume load. The load remains connected to Source One unless a Source One failure is sensed. In the Source Two position, the Source Two generator set has priority to run and assume load. The load remains connected to Source Two unless a Source Two failure is sensed. Regardless of the Source Selector Switch position, if one of the generator sets fails to operate within a selected range of voltage (and optionally frequency), the control automatically starts and connects the other generator set.

Utility to Utility

Use of multiple utility service is economically feasible when the local utility can provide two or more service connections over separate lines and from separate supply points that are not apt to be jointly affected by system disturbances, storms, or other hazards. It has the advantage of relatively fast transfer in that there is no 5–15 second delay as there is when starting a standby engine–generator set. A separate utility supply for an emergency should not be relied upon unless total loss of power can be tolerated on rare occasions. The supplying utility will normally designate which source is for normal use and which is for emergency. If either supply is not able to carry the entire load, provisions must be made to drop noncritical loads before transfer takes place. A manual override of the interlock system should be considered so that a closed transition transfer can be made if the supplying utility wants to take either line out of service for maintenance or repair and a momentary tie is permitted. Otherwise, use of engine generator sets is recommended. Also, in some installations, such as hospitals, codes require on–site generators.

The utility–to–utility control automatically directs transfer of the load from one utility power source to another, providing power with only a brief interruption during

Utility to Utility (cont'd)

contact transfer time when using open transition switches. The basic functions are similar to the other automatic controls, except there is no start/stop signal circuit, and as follows. A Source Selector Switch selects which source is preferred and which source is the backup. In the Source One position, the Normal power source supplies the load power. In the Source Two position, the Emergency power source supplies the load power. Regardless of the Source Selector Switch position, if the utility source to which the load is connected fails, the control will automatically transfer the load, provided the other source is acceptable as determined by the settings of the voltage sensors.

This is a potential application for closed transition equipment only if the utility will allow parallel operation of the two utility feeds. A "no load break" transfer can then be used to transfer a facility between two available supplies at either the utility's or facility's desire. Perhaps even more frequently, solid state switches are used to accomplish a nearly seamless transfer in these applications.

Source Monitoring

Undervoltage

An automatic transfer switch uses undervoltage sensors to continuously monitor the normal power source and the emergency power source. Control logic is provided so that the normal source is the preferred source and therefore the normal switch position if acceptable to the source monitors. The automatic transfer switch control will not permit the load to be disconnected from both sources simultaneously when either or both are acceptable to the monitors.

NOTE: NFPA 110 has a source monitoring requirement to sense undervoltage on all ungrounded lines of the normal power source and at least one ungrounded line of the generator set source.

Single phase sensing is used on single–phase sources. On three–phase systems sensing may be 1) single–phase on normal and emergency, 2) three–phase on normal and single–phase on emergency, or 3) three–phase on both sources. Single–phase sensing on a three–phase system would only be recommended in applications where possible loss of a single phase would not cause problems with the connected load equipment. See also Loss of Single Phase Detection.

Undervoltage sensing uses two parameters for determination of condition and action, a pickup and dropout setting, The pickup setting determines the voltage that the control will consider acceptable for the transfer switch contacts to close on the source and connect the load. The dropout differential setting determines the voltage that the control will consider unacceptable and initiate a transfer operation towards the opposite source. The pickup and dropout settings may be fixed or adjustable depending on the control type. If fixed, typically the pickup setting will be 85% of the nominal system voltage and the dropout differential setting will be fixed at 75% of the pickup setting. If adjustable, the pickup setting range is typically 85 to 100% of nominal system voltage and the dropout range is

Undervoltage (cont'd)

75 to 98% of the pickup setting.[2] See **Figure 19**.

The undervoltage sensors include a brief time delay before signaling the control to begin the Start Time Delay. This time delay allows the control to ignore very brief voltage dips that may result from short–circuit faults and re–closure operation, etc. Undervoltage sensing time delay can be either fixed, typically at 0.5 seconds or so, or adjustable, typically from 0.1 to 1.0 seconds.

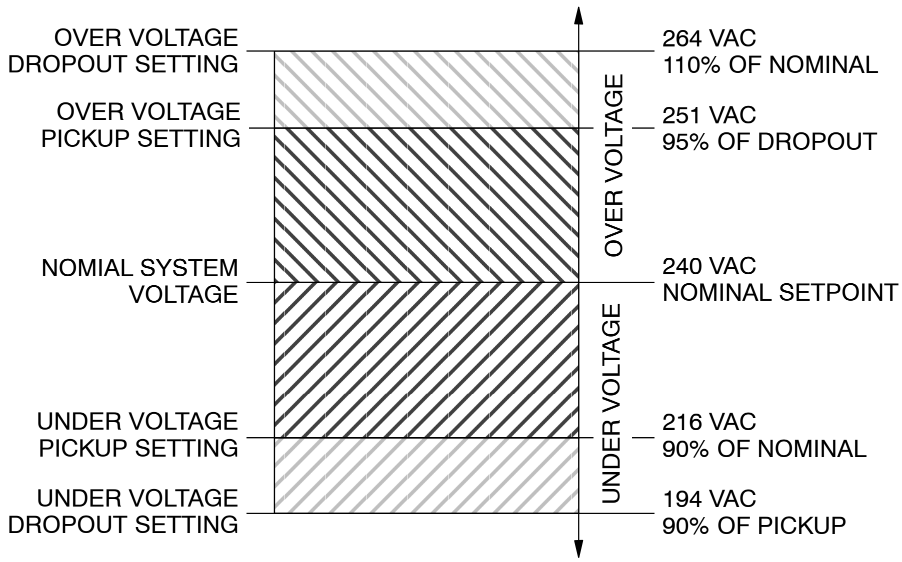

Figure 19. Over/Under Voltage Settings.

Figure 19 shows an example of undervoltage and overvoltage settings based on a 240–volt system with pickup and dropout percentages as noted. In this example a generator start would be initiated at 194 volts (90% of pickup) and transfer sequence completed if the voltage remains below 216 volts (90% of nominal). When the normal (or preferred) source voltage rises above 216 volts, the retransfer sequence would be initiated (and completed assuming the voltage remains within the undervoltage and overvoltage dropout settings). Similarly, if the system voltage reached 264 volts (110% of nominal) the start/transfer sequence would be initiated after time delay. When the system voltage returns to within 251 volts (95% of dropout) the retransfer sequence would begin.

The wide range in voltage between the pickup voltage setting and the minimum dropout voltage (75% of pickup) is used where line voltages are poorly regulated or not stable enough to stay within a close differential setting. This prevents repeated pickup and dropout and frequent starting and stopping of the generator set and transfer of the load.

Many applications require more precise voltages for reliable operation of the connected load equipment and require the use of tighter windows for these settings. In those applications, the utility line voltage should be stable enough under normal conditions to stay above the product of the pickup and dropout settings.

The end–user or consulting engineer should determine the optimum settings of the voltage sensors after analyzing both the normal source voltage characteris-

2 Setting on PowerCommand transfer switches from Cummins Power Generation are selectable within the ranges listed using the transfer switch digital display or the PC service tool.

Undervoltage (cont'd)

tics and the voltage requirements of the load equipment. In general, the pickup voltage setting should be reasonably low, and the dropout setting reasonably high. Typical close voltage settings are 90 to 95% for both the pickup and dropout differential. These settings would result in a range of dropout voltage from 80 to 90% of nominal voltage. See **Table 1** for typical steady–state voltage tolerances of common load equipment.

EQUIPMENT	VOLTAGE	FREQUENCY	COMMENTS
Induction Motors	+/– 10%	+/– 5%	Low voltage results in low torque and increased temperature. High voltage results in increased torque and starting amps.
Coils, Motor Starters%	+/–10	N/A	The holding force of a coil and its time constant of decay are proportional to the ampere–turns of the coil. Smaller coils may drop out within these tolerances for transient dip. A transient voltage dip of 30 to 40 percent for more than two cycles may cause coil dropout.
Incandescent Lighting	+10%, –25%	N/A	Low voltage results in 65% light. High voltage results in 50% life. Low frequency may result in light flicker.
Fluorescent Lighting	+/– 10%	N/A	High voltage results in overheating.
HID Lighting	+10%, –20%	N/A	Low voltage results in extinguishment. High voltage results in overheating.
Static UPS	+10%, –15%	+/– 5%	No battery discharge down to –20% voltage. UPS are sensitive to a frequency change rate (slew rate) greater than 0.5 Hz/sec. Oversizing of the generator may be necessary to limit harmonic voltage distortion.
Variable Frequency Drives (VFD)	+10%, –15%	+/– 5%	VFD are sensitive to a frequency change rate greater than 1 Hz/sec. Oversizing of the generator may be necessary to limit harmonic voltage distortion.
If voltage does not recover to 90 percent, undervoltage protective devices may lockout, overcurrent devices may interrupt, reduced voltage starters may lockout or step and motors may stall or not have acceptable acceleration.			

Table 1. Typical Voltage and Frequency Tolerances

Overvoltage

An automatic transfer switch control may be provided with overvoltage sensors. Sensors continuously monitor line–to–line voltages, single–phase on single–phase systems and three–phase on three–phase systems of both sources.

Overvoltage (cont'd)

As with undervoltage, two settings are used for overvoltage sensing, a pickup and dropout setting. The pickup setting determines the voltage that the control will consider acceptable for the transfer switch contacts to close on the source and connect the load. The dropout setting determines the voltage that the control will consider unacceptable and initiate a transfer operation towards the opposite source. The pickup and dropout settings are fixed or adjustable. When adjustable, the dropout setting range is typically 105 to 135% of nominal system voltage and the pickup range is 95 to 100% of the dropout setting.

The overvoltage sensors include a time delay before signaling the control to begin the Start Time Delay. This time delay allows the control to ignore brief overvoltages that may result from switching surges, lightning induced surges, static discharges, etc. Typically this time delay is adjustable from 0.5 to 120 seconds[2].

Electrical systems are subject to disturbances of many types that unavoidably produce overvoltages, which may or may not be damaging to load equipment. Overvoltages have many different characteristics in terms of rate of voltage rise, voltage magnitudes, and duration. A means other than transfer to an alternate power source would be required for protection from transient overvoltages that result from lightning induced surges, switching surges, etc.

For the purpose of transfer switch selection and application, only repeated or prolonged overvoltages that could damage insulation and/or equipment are a concern. Most causes of prolonged overvoltages can be effectively addressed by grounding the system neutral. On ungrounded low voltage AC systems, repeated or prolonged overvoltages may be caused by:

1) Contact with a higher voltage system (primary–secondary shorted transformer),
2) Unintentional connection of inductive reactance to ground (motor winding short to ground),
3) An intermittent arcing ground fault,
4) Others.

Over/Under Frequency

An over/under frequency sensor may be used to monitor either or both the normal and emergency power sources. Frequency sensing is seldom used to monitor a commercial utility power source, but often used to monitor one ungrounded line of a generator set. Frequency sensing on one ungrounded line of an emergency generator set is required by codes such as NFPA 110. NFPA 110 requires that transfer to the generator set be inhibited until there is adequate voltage and frequency to serve the connected load equipment.

Over/under frequency sensors typically operate with an adjustable pickup bandwidth of ± 5% to ±20% of nominal. In some switch control designs, the nominal frequency is selected as either 50 Hz or 60 Hz. In microprocessor controls this is typically selectable between 45 and 60 Hz. A dropout bandwidth is set wider than the pickup bandwidth. Depending on the automatic transfer switch equip-

Over/Under Frequency (cont'd)

ment selected, the dropout bandwidth is either fixed or adjustable, typically in the range of 1 to 5%. An adjustable dropout time delay with a typical range of 0.1 to 15 seconds allows the control to ignore momentary dips or rises in frequency.

Loss of Phase

In applications where a large part of the connected load equipment is induction motors, the undervoltage sensors may not detect the loss of a single phase. If a single phase is open, voltage on that phase may be held up at a relatively high value due to generator action of connected motors. Depending on the pickup setting of the undervoltage sensor on the open phase and the regenerated voltage on that phase, the loss of the phase may not be detected and the motor(s) may operate to damage. Loss of single–phase detection addresses this problem by detecting a drop in the relative phase angle between the three–phases. Typically, balanced three–phase voltage sources have relative phase angles of 120° ± 2°.[3]

Voltage Unbalance

Voltage unbalance detects an unbalanced voltage on a three–phase voltage source. It is not available on single–phase systems. A voltage Imbalance Sensor can be set to monitor the sources individually. Unbalanced phase voltages commonly occur because of open delta transformer connections, or unequal single phase loading. If the utility source is not an open delta transformer connection, then the Voltage Imbalance Sensor may be set to monitor the generator source only, assuming the generator capacity is less than the utility source. In that case, a single phase loading problem severe enough to cause voltage unbalance on the utility would cause even greater unbalance on the generator source.

The percentage of voltage imbalance is defined by the equation:

Percent Imbalance = (Maximum Voltage Deviation from V_{AVE})$\div V_{AVE}$ x 100%

For example if the three line–to–line voltages are 245, 235, and 230 volts on a nominal 240 volt system, the average voltage is 237. The percent voltage imbalance is 8/237 x 100% = 3.4%.

A Voltage Imbalance Sensor has adjustable dropout settings typically from 2 to 10%. The pickup setting is usually fixed at 10% of the dropout value. For example with a 4% dropout setting, the pickup will be 3.6%. The dropout setting initiates the transfer sequence of operation and the pickup setting would initiate the return of the switch to that voltage source. There is usually an adjustable time delay on dropout of 2–20 seconds.

In 3–phase systems, a small percentage of voltage imbalance can cause large increases in temperature rise in motors. Current unbalance at full load is six to ten times as great as voltage unbalance. The percentage of overheating caused by unbalanced voltage will be equal to twice the square of the percentage unbalance (see **Figure 20**).

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3 PowerCommand transfer switches from Cummins Power Generation are available with loss of phase sensing and if the relative phase angle between any line–to–line voltage drops below 90° the sensor detects that one of the phases has been lost and initiates the transfer sequence.

Voltage Unbalance (cont'd)

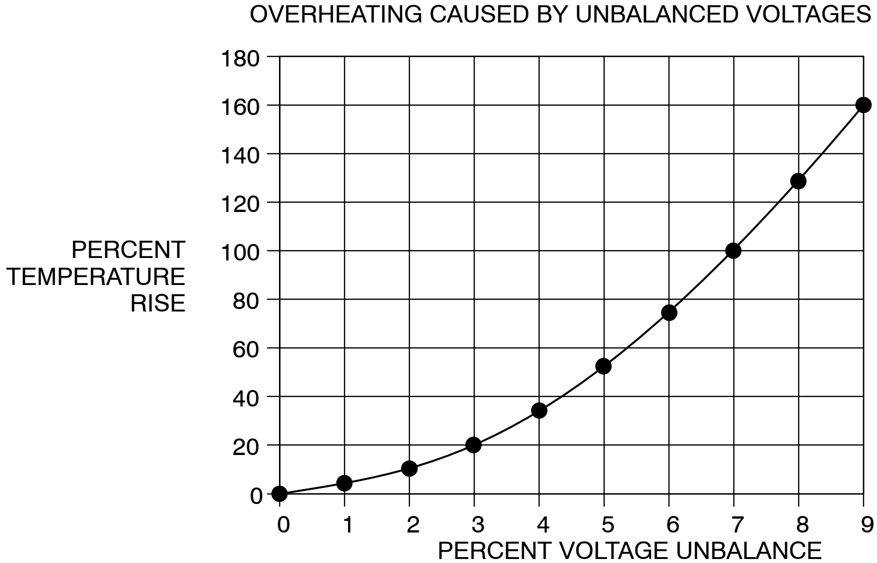

Figure 20. Motor Heating Versus Supply Voltage Unbalance.

Phase Rotation

Phase Rotation Sensing detects the phase rotation of both three–phase power sources. If the phase rotations are not the same the control considers the non–connected source unacceptable and will signal a warning.

While it is standard practice during installation to check phase rotation of both sources, this check may be mistaken or overlooked. The Phase Rotation Sensor would prevent the transfer switch from transferring to a source with opposite rotation, during installation acceptance testing or testing after system repairs.

NOTE: Phase Rotation Sensing is a transfer switch feature required by NFPA 20 for fire pump installations.

Time Delays

Time delays have been mentioned in previous sections in regard to various functions of a transfer switch but are outlined here individually.

Start

The purpose of the Start Time Delay is to avoid starting the generator or initiating a transfer sequence in the case of a short duration power outage or disturbance of the primary (normal) power source. Typically this delay is adjustable from 0 to 15 seconds or may have optional longer delay adjustability to as much as 120 seconds. Timing starts the moment the source monitors signal an unacceptable source. If the duration of the source interruption exceeds the delay time, the control signals the generator set to start.

Stop

This time delay allows the generator set to cool down at no load before being shut down. This delay is typically adjustable from 0 to 30 minutes. It begins timing when the load is retransferred to the Normal power source. At the end of the delay, the stop signal is sent to the generator set.

NOTE: The Start and Stop Time Delays are not provided on the Utility–to–Utility control.

Transfer

This brief time delay allows the generator set to stabilize before the load is applied. This delay begins when generator voltage and frequency (when used) reach acceptable limits determined by the settings of the control. After the delay,

Transfer (cont'd)

the transfer switch transfers the load to the Emergency power source. It typically has an adjustable range of 0 to 120 seconds.

Retransfer

This delay allows the Normal source to stabilize before retransfer, thus avoiding multiple transfer/retransfer cycles if the normal source is unstable. Also, this delay creates a minimum generator set operation time under load allowing for the generator set to warm up. This delay begins the moment Normal line voltage and frequency (when used) return. After the delay, the transfer switch will retransfer the load to the Normal source. In the event of generator set failure, the retransfer time delay is bypassed. Typical adjustment range is 0 to 30 minutes

Exercise and Test

Automatic transfer switch equipment controls may include a programmable exerciser clock. Generally, only one automatic transfer switch per system would be required to include an exerciser clock. The clock will automatically start and run the generator set for a selected duration at a selected time and day. The automatic controls will immediately return the switch to the normal position if the generator voltage fails during the exercise period. Exerciser clocks are generally provided with integral battery backup so that the set time of day does not change due to brief power interruptions. The automatic controls include a "with or without load" selection that will cause the transfer switch to either transfer the load or not, depending on the setting.[4] In multiple transfer switch applications, care must be taken in the system design to transfer sufficient load to the generator to meet minimum loading requirements, typically at least 30% of generator set nameplate kW.

No clock would be required in automatic and nonautomatic transfer switches that are part of a multiple transfer switch system, where at least one transfer switch has a clock. Also, in some health care facilities an automatic exerciser clock would not be required where the facility has a regular testing schedule that follows a schedule in compliance with codes.

Exerciser clock selections may include 1) no clock, 2) a programmable multi–day exerciser clock, or 3) a programmable calendar based exerciser clock. A programmable exercise clock may be selected to provide automatically repeated exercise periods at the same time on the same day of each week, month, etc. or at regular intervals. Typically stand–alone, multi–day clocks may have to be reset for daylight savings time and leap year. A microprocessor, calendar clock should take these events into account automatically.

Operator Interface

The operator interface may include various combinations of indicators; metering, displays and controls mounted on the door of the enclosure to allow closed door operation of the automatic transfer equipment. The operator interface may range from basic to comprehensive with the addition of optional features.

Indicator Lamps

A basic feature is lamp indication of source availability and switch position, provided standard on automatic and nonautomatic transfer switch equipment. Typically four lamps are provided; Normal Available, Normal Connected; Emergency Available, and Emergency Connected.

Test Switch

A means to test the transfer equipment, either a keyed switch or a sealed–membrane pushbutton switch is provided on automatic utility–to–generator set trans-

4 The switch serving the emergency system should always be set to transfer load during exercise and test to comply with NFPA Standard 110.

Test Switch (cont'd)

fer switch equipment. This control will simulate a normal power failure, start the generator set, and will either transfer the connected load, or not, depending on selected preference. An indication that the transfer equipment is actively operating in test or exercise mode is included with microcontrollers.

Retransfer Override Switch

A means to manually initiate retransfer of the load during a test, either a keyed switch or a sealed–membrane pushbutton switch, is provided on automatic utility–to–generator set transfer switch equipment.

Not–In–Automatic Indication

An indicator that the transfer equipment is not ready to operate automatically. This helps avoid inadvertently leaving the switch in a mode other than normal operating mode due to a test or service operation.

Metering

Microprocessor controlled automatic transfer equipment is normally provided with a front panel security key that disables the operator panel to prevent unauthorized changes to settings and adjustments.

Security Key

Optional metering packages are often available allowing monitoring of load side power. Typically these include voltage, current, and frequency. Microprocessor controllers will usually offer additional monitoring options including AC power and power factor. Dial indications and bar graph displays are variations available on some equipment.

Fault Monitoring

Microprocessor based control systems will often monitor the switch and power sources for events related to the settings and operations mentioned previously. Recent event storage in memory is also often included to facilitate event or problem diagnostics.

Communication

With the emergence of microprocessor control systems comes the availability of network communications between transfer switch and operator or monitor, or between multiple transfer switches. This network communication capability can be used for monitoring a switch or series of switches, initializing test modes, tracking events, and sequencing transfer events between multiple switches.

Closed Transition Transfer Control

Closed transition transfer, as described in various places in this manual, involves momentarily connecting two power sources together. With this type of switching, connections of two live power sources can occur during an exercise cycle or during return from the generator to the restored normal source after an outage. This type of switching is accomplished by monitoring the two power sources, which operate independently, and when they are within phase, voltage and frequency windows, initiating the switching action, paralleling the power sources for a brief period. Specific control functions are required to do so successfully; monitoring and requiring tight windows of acceptance for frequency, voltage and phase angle. Also, if closed transfer is aborted for any reason, and open transfer initiated, programmed transition is needed for significantly large inductive load content. If the inductive load voltages are not allowed to decay, the closure to a new power source could result in large transient events that in turn could result in the load dropping off–line or damaged equipment.

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