Choosing the Correct Transfer Switch

Daniel L. Ransom, PE
Member, IEEE
Basler Electric Company
12570 State Route 143
Highland, Illinois 62249 USA
danielransom@basler.com

***Abstract* -- Standby generation systems in low-voltage and medium-voltage applications connect to the utility power system in a number of different ways. Usually an automatic transfer switch is a part of most power system connections. Engineers can choose three-pole or four-pole transfer switches for the intertie point. Also, the application sensitivity to a power interruption during switching helps determine transfer switch selection. However, the correct one must be chosen depending upon grounding locations and neutral bonding. The transfer switch can be contactor or circuit breaker based, or can be a bypass design; at medium voltage special requirements must be considered.**

If a current-carrying conductor, even though nominally at ground potential, is connected to earth at more than one location, part of the load current will flow through the earth because it is in parallel with the grounded conductor. However, incorrect power system grounding can cause unwanted transients or hazardous multiple grounds (improper ground-fault protection), depending upon the power system arrangement.

Make certain that the power system does not have multiple separately derived sources and thus neutral grounding is at multiple locations; doing so creates unintentional current paths and defeats ground fault protection.

A transfer switch must be chosen for robust operation and for maintenance at the beginning of the design process.

***Index Terms*-- Transfer switches, ground fault protection, open transition, closed transition, separately derived sources, solidly grounded, ungrounded, high-resistance grounded**

I. Introduction

A. Basic Operation

An automatic transfer switch (ATS) performs these tasks: monitoring the power system main source, monitoring the emergency source, and transferring or retransferring power to a live, good source at an engineered time. A transfer or retransfer can also be a manual operation with or without automated assistance. There are many contactor and circuit breaker configurations that can perform these functions. As well, many simple to complex automated systems are available; nonetheless, these schemes operate in the same way as shown in Fig. 1.

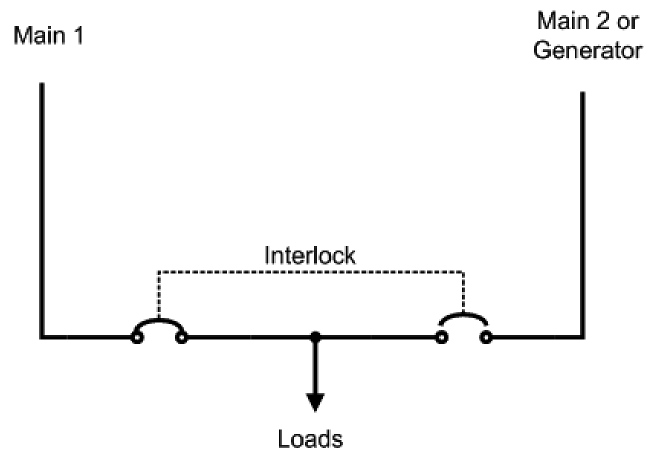

Fig.1. Basic Transfer Switch Operation

B. Switching Time

Typically, when selecting a transfer switch, the main concerns are the power disturbance time versus the cost of the transfer equipment. Local authorities via standards like the NEC (National Electrical Code)[1] also specify the manner of switching for particular applications (health-care facilities and fire pumps). Hospitals and other health-care facilities are very dependent on electrical apparatus for patient life support and treatment; the standards define specific stipulations for the equipment system, and life safety and critical branches in the emergency system, as a part of the essential electrical system.

From less costly break-before-make switches to more expensive paralleling and synchronized transfer switches power system protection methods must safeguard both the load and the generation system. This is especially true for ground faults because of the large number of line-to-neutral connected loads.

C. Solidly Grounded

Especially in systems with line-to-neutral loads and solid grounding you must be sure to provide protection against ground faults, ensuring that the ground-fault protection (protective devices and relays 50N/51N or 50G/51G)[2] sense the full fault level so these devices can act quickly. Thus human life is kept safe and costly equipment repairs and fines are avoided.

D. *Ungrounded systems*

An ungrounded system has no intentional connection between the conductors and earth ground. However, capacitive coupling exists between the system conductors and the adjacent grounded surfaces. Therefore the supposed ungrounded system is in fact a capacitively grounded system.

The reason these power systems use ungrounded schemes is to keep processes running. The operator could schedule a shutdown for fault repairs at an opportune time; thus reducing unexpected outages and resultant production losses and equipment damage.

E. *High-Resistance Ground Systems*

Where there are no line-to-neutral connected loads the NEC[1] in 250-36 (Canadian Electrical Code [3] section 10-1100) has allowed high-resistance grounding (HRG) since 1987. In ungrounded systems, failures from arcing ground faults and lack of protection detection have made HRG the preferred method for line-to-line loads. In HRG, a resistor is connected between the neutral and ground, as shown in Fig. 2.

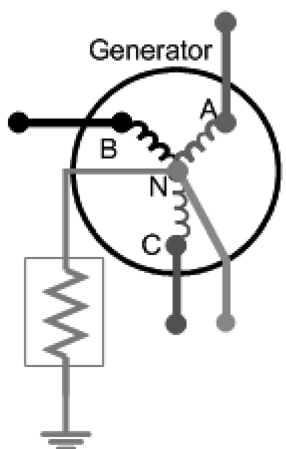

Fig. 2. Neutral to Ground Resistor for High-Resistance Grounding

An engineer selects the neutral resistance to limit the ground fault current that can flow. This can be done in a number of ways with appropriate protection. Usually the resistance is chosen to limit ground fault current to a low value, from approximately 5 A for low-voltage systems and to 50 A for medium-voltage systems, as well as limiting transient overvoltages in the power system. See ANSI/IEEE 142, Recommended Practice for Grounding of Industrial and Commercial Power Systems (Green Book)[4] and the IEEE C37.101-2006;IEEE Guide for Generator Ground Protection[5].

The initial trip is avoided and the ground fault protection provides an alarm to system operators. The system remains on line, with similar process-continuation benefits to those discussed for the ungrounded system.

As in the ungrounded system, it remains important to detect quickly and accurately this low-level ground current. Neutral bonding and grounding mistakes must be avoided so that the ground-fault protection can sense these small currents accurately.

Although regulatory agencies allow lesser-rated neutral components in transfer switches, using fully rated gear in the neutral is recommended because the ground-fault protection is measuring very low currents (requiring low impedances to make the best current measurement).

F. *General Mechanical Guidelines*

Another important aspect of choosing the right transfer switch is mechanical robustness. The switch linkages, motors, and shafts must be of sufficient quality for the task and expected switching frequency. In addition the power system neutral, if switched, must be timed correctly. Other important considerations are contact type, power handling capability; and mechanical construction and interlocking, and electronic synchronism and interlocking.

II. TRANSFER SWITCH TYPES: DELAY AND PROTECTION

Selecting the right transfer switch is difficult because each installation has many variables for which the engineer must account. These variables include the following:

- Switching delay
    - Open vs. closed transition
    - Synchronization
- Correct grounding and neutral bonding for proper ground fault protection
- Contacts rating / mechanical structure
- Maintenance and testing with minimal power system disruption

In addition there are many types of switches from a simple changeover contactor, interlocked circuit breakers, and the new single- and double-throw solid-state transfer switches (SSTS). Transfer switches are best installed as near to the load as possible; transfers are then based on power system conditions at the load.

A. *Switching Delay*

A very important variable in considering which transfer switch to employ is switching delay. Lesser expensive break-before-make devices are “open transition,” meaning the loads experience a power interruption. For a power system bus with motor loads a long open transition must occur because the voltage at the terminals of motors and other inductive loads does not return to zero immediately when disconnected from a power source. In fact, connecting a motor back to the system bus before it has “spun down” to a safe level can damage the motor shaft and can cause nuisance tripping of circuit breakers by closing out of synchronization. Upon closing some transfer switches use a simple timing scheme and dead-line load test controls the retransfer.

Transfer switch manufacturers can provide a closed transition transfer/retransfer switch that parallels the generator with the utility source when a utility outage is predicted and upon utility return for a certain time. Be sure that the equipment can handle the energy requirements of closed-transition switching. These switches incorporate a fast sync-check (25) element that monitors both sources and initiates a “soft” retransfer, avoiding out-of-phase closing. Sometimes generator governor controls match the generator and line for a faster retransfer.

If grounded and bonded correctly, closed transition can prevent damage to motor loads and nuisance tripping of breakers. Closed transition transfer switches with fast operating times can still place a heavy load step on the generator, resulting in frequency and voltage dips and long recovery times. Interconnected remedial action schemes are often employed to add back loads sequentially to lessen the impact of switching.

Employing closed transition transfer requires utility approval prior to installation. Utilities will specify protective relay functions, including ground fault protection, to protect the utility power system and avoid islanding. The task of designing and commissioning these protection systems is the customer’s, and the utility usually requires on-site inspection and testing.

B. *Correct Grounding and Neutral Bonding*

An ungrounded system features no intentional connection between the system conductors and ground. Recall that there is capacitive coupling that exists always between system conductors and ground. Because of the danger to personnel and possible damage to equipment and property if there is leakage to ground caused by shorts or high-impedance paths, the NEC [Art. 250, (B)] specifies certain grounding and bonding practices for non-current-carrying conductive materials, and that detection of faults be incorporated into power systems (the second fault performing tripping) for current-carrying conductors.

Separately derived sources [NEC Art. 100 and 250.20(D)] can be a battery (UPS), photovoltaic, generator or utility-fed transformer secondary that have no direct electrical connection, including grounding, to another system. Such a separately derived source must have its neutral grounded and conductors bonded per NEC [Art. 250 (B)]. Each power source has one reference to ground.

The complete guide for generator ground protection is IEEE Standard C37.101-2006[5]. Other references on grounding can be found in the IEEE Standard 446-1995 (Orange Book)[6], and in the IEEE Standard 142-2007 (Green Book)[3].

1): Correctly Bonded Three-Pole Design

Fig. 3 shows a correctly grounded standby generator system including a three-pole transfer switch[7]. Although the generator housing is grounded (for safety) the generator does not have the neutral bonded to ground. Only one neutral-to-ground path exists if there is a ground fault, and full currents flow allowing for complete ground fault protection. The generator is not separately derived because the neutral is common to both the normal and standby sources.

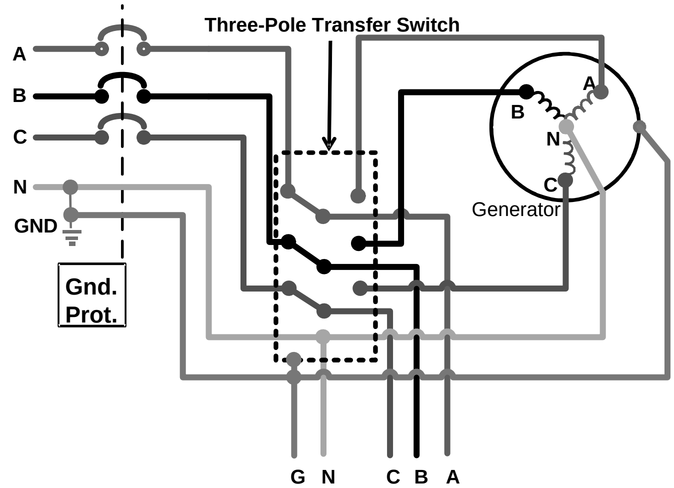

Fig. 3. Three-Pole Transfer Switch; Correctly Grounded Standby Power

2): Incorrectly Bonded Three-Pole Design

Suppose that you bond the generator neutral to the generator case while maintaining the generator case ground. In Fig. 4 the standby power source has been connected neutral to ground; while the bus is isolated from the transfer switch housing. Now the A-G ground fault currents have multiple paths. The generator in Fig. 4 is not connected to provide power via the transfer switch, yet fault current is flowing through it because of the multiple neutral-ground paths on the unswitched neutral. In this situation, the ground fault protection cannot measure the full current and might not trip for ground faults.

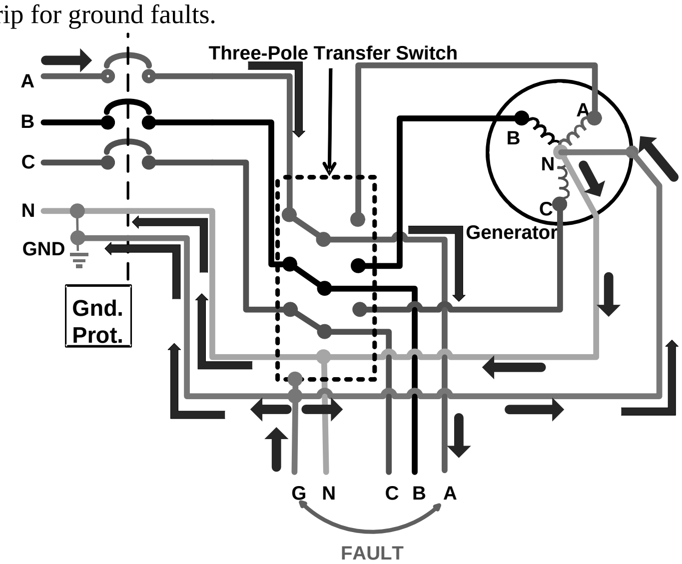

Fig. 4. Incorrectly Bonded Generator Neutral with Ground Fault

Fig. 5 shows another situation of multiple neutral to ground connections. Phase to neutral (A-N) fault currents have multiple paths because of the generator ground path. In this situation, the ground fault protection cannot measure the full current and might not trip for line-to-neutral faults.

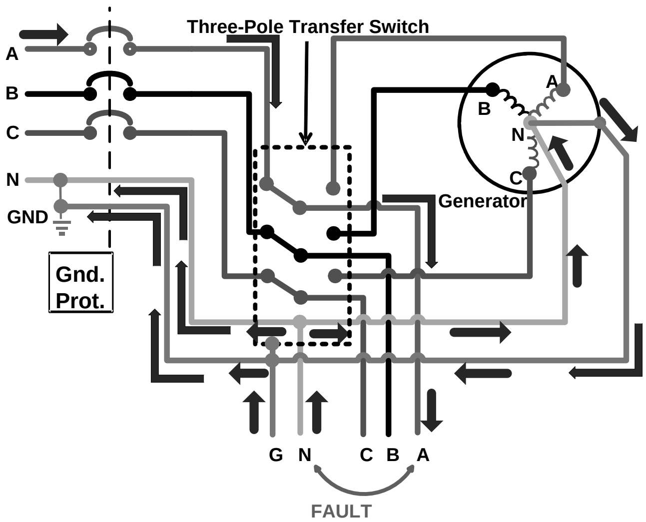

Fig. 5. Incorrectly Bonded Generator with A-N Fault

2): Possible Mitigations; Three-Pole Transfer Switch

It is possible to choose a three-pole switch with an overlapping neutral to avoid a separately derived system. However, during the time when both neutrals are connected we have the same disadvantages as a three-pole switch—desensitized ground-fault protection, plus nuisance tripping of the 50G/51G, 50N/51N ground fault protection on the de-energized source side could occur. Usually these neutral contacts are not rated for fault-duty switching and can have higher than normal resistance (making ground fault current measurement difficult).

A possible method to ridethrough this event is to delay the ground fault protection for the switching time. However, this time lengthens depending upon the switch age and switch maintenance. Delaying ground fault protection can cause injury to people and overduty damage to equipment; it is not recommended.

4): Recommended Four-Pole Transfer Switch

Selecting a four-pole transfer switch results in no ground protection split return paths (see Fig. 6). The neutral switch contacts are fault rated and timed simultaneously with the phase switches. Full current is available to ground-fault protection. Because of the open neutral at the transfer switch, the generator is a separately derived source and requires an earth ground. This type of installation keeps the transfer switching in compliance with NEC[1], NFPA[8,9] , and CE code[2] requirements.

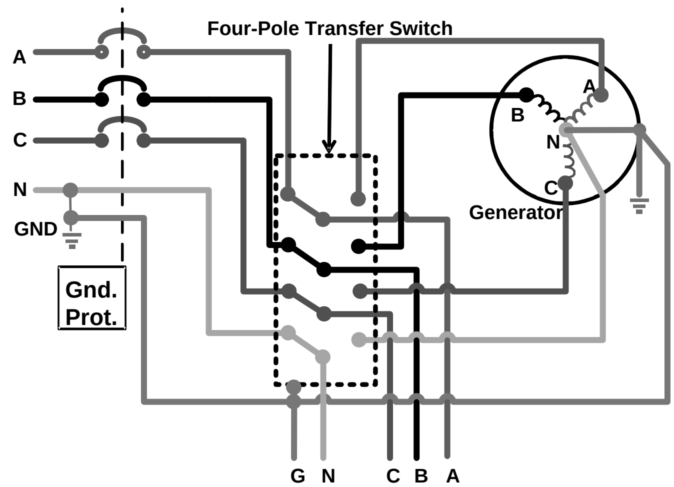

Fig. 6. Switching the Neutral with a Four-Pole Transfer Switch Gives Correct Currents to Ground Fault Protection

III. Mechanical Considerations and Backup

Performing a power system load-flow and short-circuit study helps determine the make, carry, and break capacity of the transfer switch contacts. The mechanical components must be designed for the switch expected duty cycle and for fault withstand.

Adding a backup switch or switching arrangement with redundant components is one possible answer to performing maintenance on the main transfer switch. This is especially true for high-reliability installations where a power loss is unwanted.

A. Transfer Switch Contact Ratings/Mechanical Structure

When paralleling to a live bus with no “soft” or synchronized retransfer the switch contacts must withstand a possible double-voltage (worst-case closing would be 180° out of phase on one phase). In addition dc offset from switching, which can be as much as 1.7 times the peak steady-state AC current, can add further stress to the contacts, as well as the number of inductive loads. Contacts are designed for continuous duty and are rated for all types of loads. A well-selected transfer switch has high dielectric strength, heavy-duty switching and withstand capabilities, and high interrupting capacity at all voltage levels.

These switches have positive, fast make, fast break toggle mechanisms; some switches that carry large currents (in the 1000-A and greater range) at low-voltage, and now some at medium voltage, use metal plates or non-metallic arc chutes (if available) to separate and cool the switching arcs. Most medium-voltage transfer switches take advantage of a vacuum break, thus limiting wear on the switching contacts. Lately some manufacturers are building medium-voltage switches with arc chutes; although less expensive, be sure that these will fit your needs.

B. Minimum System Requirements

When using a four-pole transfer switch, as stated earlier, it is important to have the neutral contacts switch on the same mechanism as the phase contacts. UL 1008[10] requires that the fourth pole of a transfer switch be tested and proven to have ratings equal to its phase contacts if not of the same construction. The switch can have a different means of support for the neutral bus; the objective is that it must be solidly mounted. Control of the phase and neutral switching must be from a single mechanism that switches all poles simultaneously.

The neutral contact must be capable of withstand and close into fault ratings at least equal to the phase contacts. However, not all transfer switches employing a fourth pole are constructed in this manner, so be sure to examine transfer switch specifications closely. A visual inspection is to your advantage.

1): Medium-Voltage Circuit Breaker Considerations

In discussing standards note that a transfer switch built to UL 1008 can be compared to a pair of electronically controlled circuit breakers built per UL 891[11] and UL 489[12]; these breakers performing a transfer-switch function. Comparing the 2000-A endurance ratings in the standards we see that UL 1008 uses more current (200 percent) at 500 operations at rated load whereas UL 489 is at only 100 percent of rated load (sources assumed in synch). Therefore, UL 1008 is a more stringent standard for contact rating. In addition, UL 1008 requires mechanical interlocking, useful in two-source open transfers. However, when switching medium voltages and high currents, consider using circuit breakers that are electronically controlled and interlocked. These schemes usually employ protective relays, fast communications protocols, and extensive check and lockout logic.

C. Minimal Disruption and Maintenance

IEEE 446 defines maintenance on standby power systems as the following: "The goal of preventive maintenance is to ensure that the system is in optimum operating condition. Without proper emphasis on maintenance from design stage through operation, the system can rapidly become unreliable and fail to perform its intended function."[6]. When performing maintenance a bypass switch is necessary. The bypass switch maintains power to the load while isolating the transfer switch.

Where de-energization is not practical (for example, hospital loads or critical processes) for periodic maintenance, a two-input bypass isolation switch is used. This style switch permits periodic testing and maintenance (with added cost) as shown in Fig 7.

Mechanical or automation cross interlocking between the automatic transfer switch and the bypass switch is simple and the bypass switch can be operated at any time without regard to the automatic switch position. Thus, the bypass switch can be a manual transfer device when the automatic switch malfunctions and when the automatic switch is removed from service.

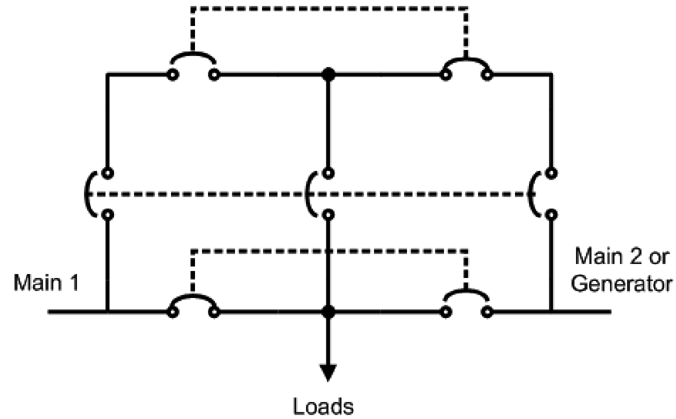

Fig. 7. Bypass Switch for Maintenance

Care must be taken to provide proper ground-fault and overall fault protection during these maintenance periods, including for arc-flash hazard protection because workers are usually in close proximity to live circuits. The bypass switch door must be closed securely when performing the drawout and bypass tasks to minimize arc-flash danger.

IV. Conclusions

Selecting the correct transfer switch involves informed choices by the specifying engineer. Following NEC, IEEE, NFPA, UL, and CSA standards assists in choosing the right equipment for the job, especially in the 1000 Vac range and less.

Protection elements have become more prevalent in the industry, especially in synchronized switching (25), and in ground fault protection (50N/51N, 50G/51G).

High-resistance ground methods can be used only when there are no line-to-neutral connected loads. Although regulatory agencies (NEC, CE Code) allow lesser-rated neutral components, using fully rated gear is recommended because the ground-fault protection is measuring very low currents (requiring low impedances to make the best current measurement).

It is important to choose the correct transfer switch based upon the local standards, whether a source can be qualified as separately derived, and the effect on ground-fault currents. A four-pole design is recommended in most applications; switching the neutral leg preserves proper operation of ground-fault protection.

Choose a robust switch with not only good phase contact ratings; it must have equal neutral contact ratings, operation mechanism, and spacings as do the phase components.

When switching medium voltages and high currents, consider using circuit breakers that are electronically controlled and interlocked. These schemes usually employ protective relays, fast communications protocols, and extensive check and lockout logic.

An electrical control/interlocking bypass system using properly rated mechanisms can be a better choice than a single transfer switch, (however at greater cost).

Maintenance should be part of the original design, with special attention to protection and the performance stipulations presented in this paper.

V. References

[1] National Electrical Code / NFPA 70.

[2] IEEE C37.2-2008 - IEEE Standard Electric Power System Device Function Numbers - Protective circuit device modeling numbering scheme for various switchgear.

[3] Canadian Electrical Code, CSA C22.1.

[4] IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems, IEEE Standard 142-2007 (Green Book).

[5] IEEE STD 37.101-2006, Guide for Generator Ground Protection.

[6] IEEE Recommended Practice for Emergency and Standby Power Systems, IEEE Standard 446-1995 (Orange Book).

[7] Nash, H.O., Jr.; "Ground-fault protection and the problem of nuisance tripping of critical feeders," I&CPS Technical Conference, 1988. Conference Record, Papers, pp.20-35, 2-5 May 1988

[8] NFPA 110, Standard for Emergency and Standby Power Systems—2010.

[9] NFPA 111, Standard on Stored Electrical Energy Emergency and Standby Power Systems—2010.

[10] UL1008, Standard for Transfer Switch Equipment, 2011.

[11] UL 891, Switchboards, Edition 11—2005.

[12] UL 489, Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures—2009.

VI. Vita

Daniel (Dan) Ransom, PE has 40 years of industrial and utility electronics experience; including many years in protection development and application support. He has extensive experience in consulting engineering for power and communications systems. Dan is an engineering graduate (BSEE) of Gonzaga University, Spokane, Washington; he also holds a liberal arts degree from Washington State University. He is a member of the IEEE IAS (Industry Applications), PES (Power Engineering), Communications, and Standards societies. To date he has one US patent. He is a Professional Electrical Engineer in numerous states. Dan joined Basler Electric in 2010 and is Principal Application Engineer covering the West Coast region.

Basler Electric®

www.basler.com

Highland, Illinois USA
Tel: +1 618.654.2341
Fax: +1 618.654.2351
email: info@basler.com

Suzhou, P.R. China
Tel: +86 512.8227.2888
Fax: +86 512.8227.2887
email: chinainfo@basler.com