500KV IPT BREAKER FAILURE PROTECTION

An Application of Dual Timer Scheme for Short Critical Clearing Time

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Abstract

Circuit breaker failure protection scheme is typically used in electric transmission system to provide backup protection against any fault occurring at any given time in case a circuit breaker fails to open following receiving a trip signal from system protection relays. An ideal breaker failure protection system should clear the fault by operating the least amount of contributing breakers, both locally and remotely, within a desired time frame that does not cause the system to become unstable. In general such scheme can be applied with proper timing coordination including safety margin before approaching the system critical clearing time. A system critical clearing time is defined as the time duration that a fault can remain on the system before system instability occurs.

In Progress Energy Florida, a system planning study for a future scenario recommends its 500kV transmission system critical clearing times to meet 8 cycles for single-line-to-ground fault and 5.5 cycles for multi-phase faults. Challenged by such tight requirements, the Company's Transmission Protection and Controls (T-P&C) engineers have developed a 500kV breaker failure (BF) protection scheme that implements dual BF timer logics:

- A single phase fault detector with a typical timer
- A multi-phase (three-phase or phase-to-phase) fault detector with a shorter timer

This paper presents how Progress Energy T-P&C engineers develop the dual-timer BF scheme by utilizing the associated state of the art protection system, equipment, and communication facility to meet short duration system critical clearing time while achieving operational speed, selectivity, and sensitivity.

Introduction

Progress Energy (NYSE: PGN), headquartered in Raleigh, N.C., is a Fortune 500 energy company with more than 22,000 megawatts of generation capacity and approximately $10 billion in annual revenues. Progress Energy includes two major electric utilities that serve about 3.1 million customers in the Carolinas and Florida. The company has earned the Edison Electric Institute's Edison Award, the industry's highest honor, in recognition of its operational excellence, and was the first utility to receive the prestigious J.D. Power and Associates Founder's Award for customer service.

Progress Energy Florida (PEF) serves approximately 1.6 million customers in central Florida. The company operates 4700 miles of transmission lines including 69kV, 115kV, 230kV, and 500kV voltage classes, one 860MW nuclear generating unit, an additional 13,000 MW from coal, combustion & oil base generating capacity, and five 500kV/230kV substations. 230kV and 500kV systems are the most critical transmission asset to PEF because they represent the company's transmission backbone that directly interfaces with the majority of power generating units.

In general PEF transmission infrastructure consists of transmission lines, autotransformers, generator step-up units (GSU), capacitors/reactors, and substation bus works. Where applicable the transmission systems are protected via redundant high-speed relaying systems powered by independent DC load center; whereas circuit breakers are independently provided by one breaker failure protection relay and one breaker control relay.

Since the main topic focuses on 500kV IPT (Independent Pole Tripping) circuit breaker failure protection, the rest of this paper will be addressing 500kV system protection and control only.

A Need for Breaker Failure Protection

Circuit breakers do fail! There are many reasons that cause a circuit breaker to fail to open when initiated by the associated protective relay(s) under system fault condition. In PEF 500kV transmission system where power system stability is a vital factor, provision of effective fault clearing operations can avoid damaging substation apparatus, tripping additional transmission lines, transformers, generator units, or resulting in undesired power outages and even massive blackout.

In addition to performing scheduled maintenances on circuit breakers in order to keep them in good working condition, PEF applies a dedicated breaker failure protection scheme as a back-up protection relaying to insure a stable transmission system. When every protective equipment functions properly, a fault shall be interrupted by designated circuit breakers as soon as possible. But if any breaker fails to operate as directed, its corresponding breaker failure protection scheme shall be activated to trip the least amount of contributing breakers, both locally and remotely, within a desired time frame prior to reaching the system critical clearing time. A system critical clearing time is referred as the time duration that a fault can remain on the system before the power system becomes unstable.

With proper design of breaker failure protection, system faults can be quickly isolated such that the impact is minimized to the rest of the transmission system and to the customers.

The Current BF Protection Scheme

Figure 1 shows a simplified, typical one-line diagram of PEF 500kV transmission substation. Each circuit breaker (CB) is equipped with a dedicated breaker failure (BF) protection relay. Use CB #2 (2-cycle operation, dual trip coil) as an example, under “normal” condition it is tripped by the following system fault scenarios:

- 500kV transmission line L1 fault
- 500kV Bus #3 fault
- 500-230kV autotransformer fault

Once a protective relay’s tripping signal is issued to CB #2, a breaker failure initiate (BFI) signal is also simultaneously issued to the CB’s dedicated BF protection relay 50BF2. The 50BF2 relay has two internal core logics: a fault detector that senses whether the fault still remains in the system, and a BF timer that is set to coordinate with the critical clearing time at the station before harmful effects on the system occurs.

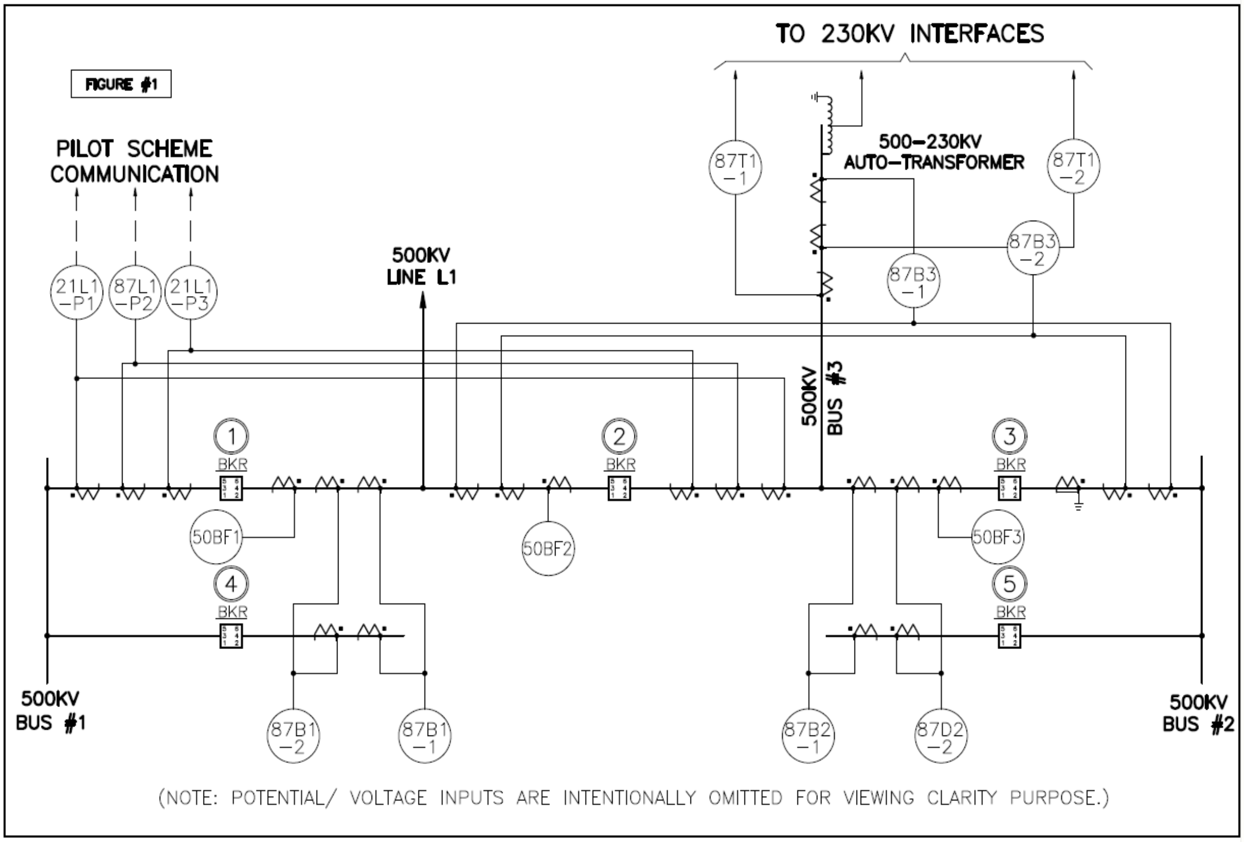

Figure 1: 500kV Single Line Diagram

Refer to Figure 2 for a typical BF scheme. If CB #2 trips as anticipated, the system fault is isolated, the built-in 50BF2 fault detector logic is reset and hence the whole BF process stops. If CB #2 does not trip after the pre-set BF timer times out, a breaker failure condition on CB #2 is declared. The 50BF2 relay will have the following operations:

- Trips local 500kV CB #1 and CB #3 (also attempts to re-trip CB#2)
- Trips local 230kV breakers that electrically tie to the autotransformer
- Trips via Direct Transfer Trip (DTT) scheme the remote 500kV CB's that electrically tie to Line L1

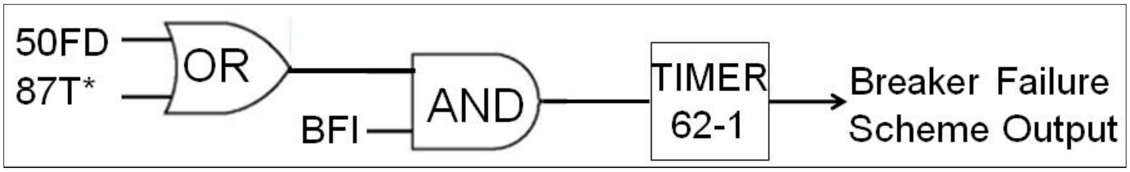

Figure 2: Typical Breaker Failure Scheme Logic

Note the BF scheme is applicable and initiated under system fault condition only. BFI shall not be activated under manual operations, whether it is done locally or remotely via SCADA.

The 87T function may also be used as fault detector for transformer faults not readily seen by the over-current elements.

Components of Breaker Failure Timer

Figure 3 illustrates the total time required to clear a fault under BF condition. The BF timer needs to be set to include a safety margin such that the BF protection relay would achieve both operational sensitivity and selectivity purposes. Namely, it operates when a circuit breaker failure is affirmative and avoids tripping other contributing breakers if the fault has been cleared prior to BF timer expiration.

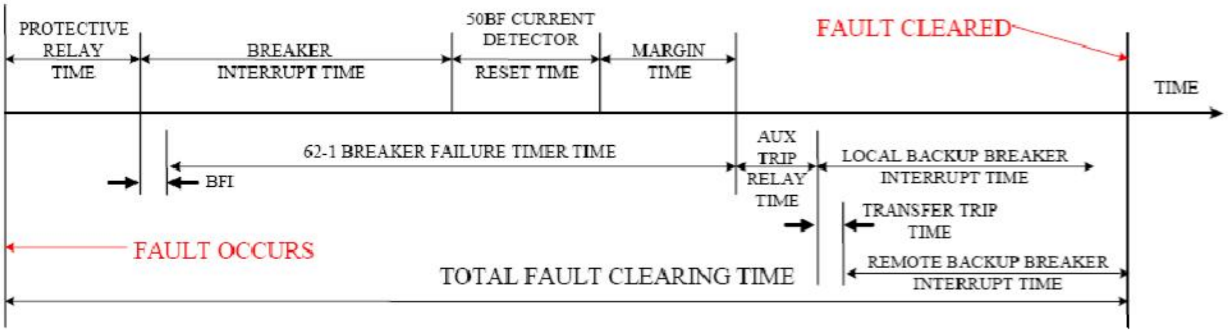

Figure 3: Breaker Failure Scheme Timing Diagram

In the whole BF timing scheme (measured as clock cycles in 60Hz system, to be the same throughout this paper) all other parameters are usually known except for the safety margin time. To determine the safety margin time, the following equation is used:

$T_s = T_t - (T_{pr} + T_{bkr} + T_{50} + T_{aux} + T_{bu} + T_c)$, where

- T_s: Safety margin time
- T_t: Total maximum fault clearing time
- T_{pr}: Protective relay operating time (2-cycles typical)
- T_{bkr}: The failed breaker operating time (2-cycle typical)
- T_{50}: 50BF current detector reset time (1-cycle typical)
- T_{aux}: Auxiliary relay operating time (0-cycle typical, not used in 500kV system)
- T_{bu}: Local and remote contributing breaker operating time (2-cycle typical)
- T_c: Transfer trip channel delay time (0.5 to 2-cycle typical over fiber optic network)

The maximum total fault clearing time (T_t) shall not exceed the critical clearing time; otherwise system will become unstable. If T_t is given as 12 cycles, then the safety margin time is:

$$T_s = 12 - (2 + 2 + 1 + 0 + 2 + 0.5) = 4.5 \text{ cycles}$$

Hence the BF timer setting equals $(T_{bkr} + T_{50} + T_s) = 7.5$ cycles.

The Challenge

In 2008, a transmission system planning study for a future scenario that includes an additional 2200MW nuclear generating capacity and a major transmission system enhancement will require PEF 500kV system to meet the following breaker failure contingencies:

- 8-cycle critical clearing time for single line to ground faults, and
- 5.5-cycle critical clearing time for multi-phase faults.

The proposed new nuclear generating units will be located 8 miles from the existing one. They will be interconnected by a 500kV transmission line. Because of the short distance between two nuclear generating plants, the units are virtually tied to a low impedance bus. Once a disturbance occurs on the 500kV system, these nuclear units may experience an undamped response or oscillate together to become transiently unstable if the disturbance is not cleared in a timely manner. It is found that the above recommended short duration critical clearing time would avoid wide spread system collapse from occurring.

PEF's Solution

The faster recommended critical clearing time requirements make it impossible for PEF T-P&C design to meet by applying the conventional BF protection scheme given above even if the safety margin timer is set to zero (T_s = 0.0 cycle). The major effort for T-P&C engineers is how to reduce the overall timing as to achieve:

- $T_t \leq 8.0$ cycles for single-phase faults, or
- $T_t \leq 5.5$ cycles for multi-phase faults.

The first approach is to utilize fast tripping protection relays so that relays can operate within 1 cycle. These relays are equipped with enough solid state output contacts for direct tripping the breakers and direct issuing BFI signals; hence there is no need for including auxiliary tripping relays in the circuit. In addition PEF acknowledges the communication channel needs to be improved in order to perform remote terminal direct transfer trips (DDT). Therefore the existing communication media including power line carrier, micro wave, and leased telephone line will be replaced with fiber optic network type, either over dedicated direct connect fiber optic cable or over a self-healing (ring) multiplexor system. DTT utilizes the same communication channels reserved for transmission line protection pilot schemes to direct trip and lock out the remote contributing breakers via the pilot protection relays. This implementation will present at least two advantages:

- Increase operation speed by not needing dedicated tripping relays at remote terminal
- Achieve true redundancy in communication channel since there are 3 redundant pilot schemes per 500kV line

The second approach is to consider the concept of saving the reset time inside the BF protection relay by slightly revising the logic sequence of the BF scheme, as illustrated in Figure 4. This approach will allow the 62BF to time out first and proceed to operate the BF scheme if the fault detector 50BF still persists. The benefit is to eliminate the guess work of determining the length of 50BF reset time while securely reserving the operating integrity of all vital components in the BF scheme.

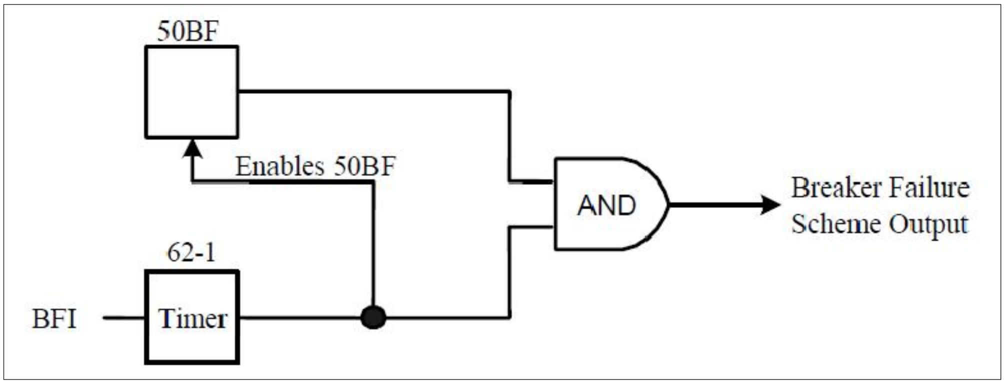

Figure 4: Revised Breaker Failure Scheme

By this far, $T_{pr} \leq 1$ cycle, $T_{aux} = 0$ cycle, $T_{50} = 0$ cycle, $T_c \approx 0.5$ cycle, and

$$T_t \leq T_{pr} + T_{bkr} + T_{50} + T_s + T_{aux} + T_{bu} + T_c$$

$$T_t \leq 1 + 2 + 0 + T_s + 0 + 2 + 0.5 = (5.5 + T_s) \text{ cycles}$$

The revised BF scheme would only satisfy 8-cycle single-phase type of faults if the safety margin time is set at $T_s = 2.5$ cycles. Hence the revised BF timer setting equals $(T_{bkr} + T_s) = 4.5$ cycles.

The third approach is to specify 2-cycle independent pole trip (IPT) circuit breakers. IPT breakers are not used for tripping an individual pole on the corresponding phase fault. IPT breakers always trip all three poles regardless of any type of faults. The main application is taking the advantage of the probability that, with independent tripping mechanism of an IPT breaker, mostly one pole would fail at a time. Even if a multi-phase fault occurs but the only one breaker pole fails to open, the fault is seen as transforming into a single-phase type.

What if, in an extreme scenario, two or three poles fail to open? This is actually the case in IPT breaker manufacture design. When a breaker experiences a mechanical problem including super low SF_6 gas level (fast leakage) or loss of spring charge condition, it will block all 3-pole operation and remain/lock in its current position. Then a Class-1 alarm is generated to notify the company system operation and maintenance department to immediately isolate the failed breaker for repair. Although rare, if a breaker experiences an unattended mechanical problem, it will apply a BF arming logic to bypass opening up itself while being asked to trip for a multi-phase fault. This concept is expanded to include other type of failure conditions that prevent the breaker from tripping more than two poles. A new scheme is developed to implement dual timer logics in the BF relay, as shown in Figure 5.

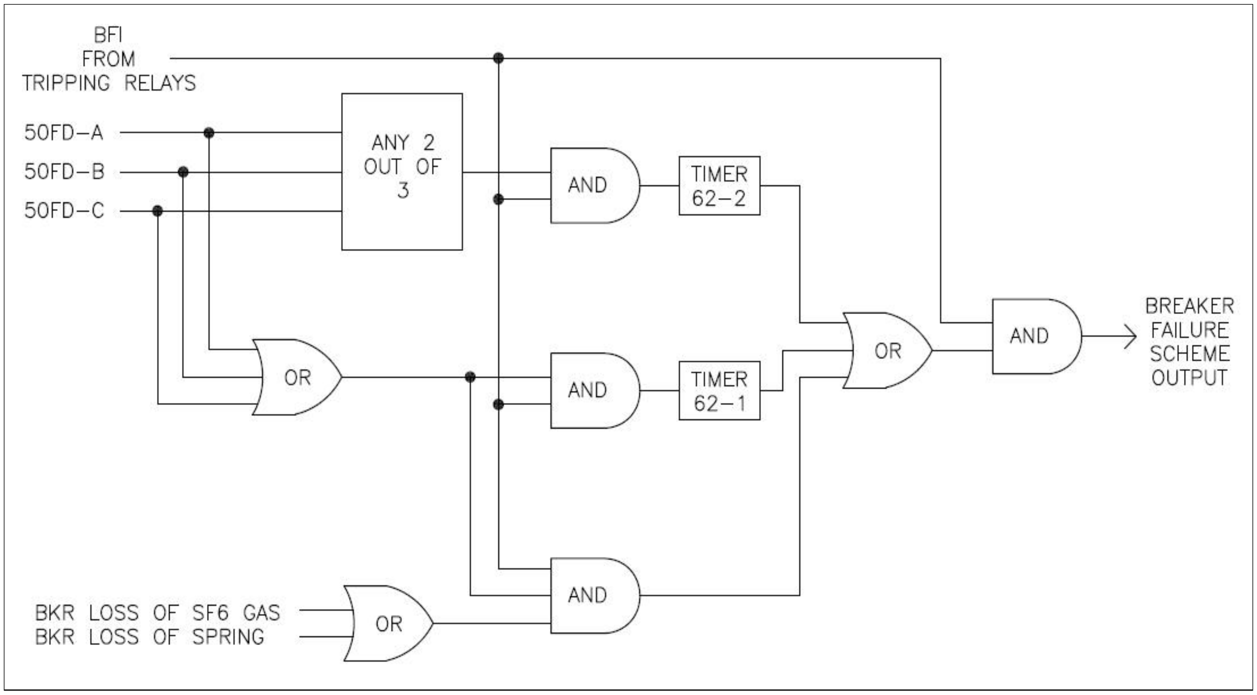

Figure 5: The Dual Timer Breaker Failure Scheme

The dual BF timer scheme logics are summarized below:

1) Single-phase fault logic with a typical timer 62-1. It covers the most likely a single-phase fault in nature or one failed pole of the IPT breaker. The BF timer is set to 4.5 cycles and the critical clearing time becomes $T_t \leq 8.0$ cycles.

2) Multi-phase fault logic with a shorter timer 62-2. It addresses two co-existing conditions: an IPT breaker fails to open any two of three poles AND a multi-phase (LL, LLG, and 3LG) fault occurs in the protected zone of that breaker. The BF timer is reduced to 2.0 cycles and $T_t \leq 5.5$ cycles.

(T_{pr} + T_{bkr} + T_{bu} + T_c = 5.5 cy) Note there may be a concern on the shorter BF timer (2.0 cycles) that does not give sufficient margin to avoid over-tripping the contributing breakers. However during a visit to the IPT breaker's manufacture facility, T-P&C engineers witnessed factory testing with results of T_{bkr} ≈ 1.5 cycles. It is highly confident that the involving breakers (local and remote) have operating time of less than 2 cycles; thus the overall BF scheme time would not exceed 5.5 cycles.

3) Severe breaker mechanical problem logic to bypass all BF timers. An unattended breaker SF_6 gas leakage or a complete loss of spring charge condition triggers a lockout condition on breaker operation. This along with BFI signal and fault detector supervision will trigger a BF action. There is no need to wait for BF timer expiration if the breaker's operation has been disabled (T_t = T_{pr} + T_{bu} + $T_c \leq$ 3.5 cy).

Conclusion

The recommended short duration critical clearing time in 500kV transmission system presents a huge challenge to PEF T-P&C engineers but provides an opportunity for PEF to improve its transmission infrastructures. It also enhances the PEF engineering experience for brainstorming to come up with the workable solution. The implementation of dual timer logics in the BF protection scheme requires the following 500kV design criteria to be met:

- IPT circuit breakers with less than 2-cycle operating time,
- Relays for the protection of line, substation bus differential, and autotransformer to be sub-cycle type with enough fast acting outputs for direct tripping and BFI,
- Utilization of fiber optic network to ensure faster channel time for direct transfer trip purpose,
- Elimination of auxiliary tripping relays,
- Dedicate BF protection relay to be sub-cycle type with the provision of:
  - the ability to sense and distinguish different type of fault
  - user definable timing logics
  - BF timer safety margin
  - adequate count of fast acting outputs

One future trend worth consideration is the application of relay peer-to-peer communication among the substation IED's could further help reduce the overall BF scheme time. PEF is highly confident that, with today and future technology, the development of breaker failure protection will become less difficult to meet the recommended short duration critical clearing time on its 500kV system while achieving relay operational speed, selectivity, and sensitivity.

Biographies:

Jorge L. Pardo, P.E., F.NSPE, was a co-author of this article in his present position as Lead Engineer in the the P&C Engineering Standards Unit at Progress Energy Florida. He graduated in 1972 with a BSEE from the University of Pennsylvania, Moore School of Electrical Engineering. He has also attended various post graduate programs such as Penn State's Insulation Coordination certificate program. He has spent 30 years in various capacities of engineering at FPL Co., including field engineering, drafting & wiring support and project engineering. He changed jobs to Progress Energy Florida in 2001 where he has spent an additional 10 years in the P&C field.

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