# *Medium Voltage Collection Circuit Breaker with Mechanically Interlocked Grounding Switch Provides Better Safety and Reliability for Wind and Solar Plants And Their Personnel than Remote Transfer Trip*

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***Abstract- The medium voltage circuit breaker with mechanically interlocked grounding switch (aka "grounding breaker") and remote trip protection techniques provide unique forms of protection. In this paper, remote transfer trip and grounding breaker protection techniques are compared.***

***Damage due to faults in collection circuits happens fast. Remote transfer trip relays that protect the feeder circuit breaker are programmed to delay the trip signal, take more than seven cycles to operate, add deadly incident energy, or operate so quickly that destructive temporary overvoltage (TOV) occurs.***

***If each feeder breaker on each collection circuit is interlocked with a grounding switch, most, if not all, of the problems seen with remote trip (including grounding transformers) are resolved. This paper reviews the background, design, and operation of the grounding breaker and remote and transfer trip with PSCAD and compares the performance of the two schemes.***

***This paper shows remote trip is a good protection technique; however, breaker designs that do not ground within wind and SPPs leave the collection circuit floating. The grounding breaker is faster, significantly lowers the incident energy, and keeps the TOV duration under the prior duty curve of the surge arrester where other remote trip schemes do not. The conclusion proposes grounding breaker applied in the design and construction of power-generating projects, such as WPPs and SPPs, constitutes the best practice.***

***Keywords- combined breaker, grounding switch, remote, transfer trip, WPP, SPP, arc flash, blast, temporary overvoltage, surge arrester, collection circuit, transformer, single line to ground fault, insulation coordination.***

## 1. INTRODUCTION

Although the interlocked-combine breaker grounding switch (aka "grounding breaker") and remote and transfer trip provide protection, the grounding breaker is essential. Faults in collection circuits and the damage created happen fast. The grounding breaker provides more forms of protection in a single unit with less delay than other types of breakers. The grounding breaker operates and protects solar and WPPs by reducing incident energy and avoiding temporary overvoltage (TOV). When TOV is eliminated during the opening of the feeder circuit breaker, the surge arrestors are operated below their prior duty curve, insulation coordination of the feeder circuit is maintained, and the equipment is more reliable. This paper discusses remote trip and the grounding breaker in terms of the TOV.

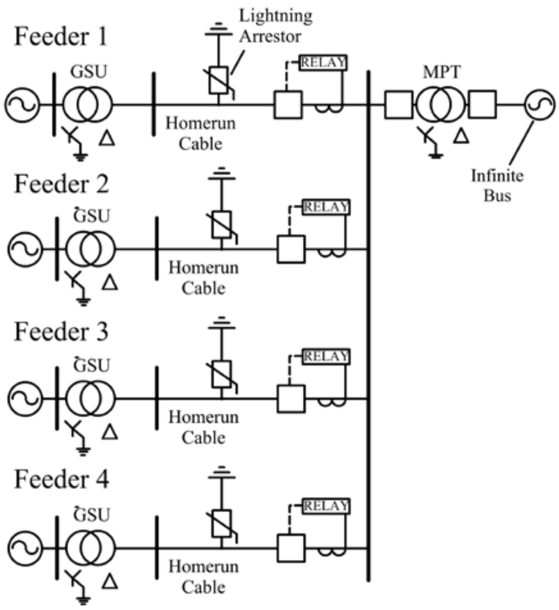


Fig. 1: WPP Single Line w/o Grounding breaker.

First approach, the remote transfer trip within WPPs (aka "WPP") or SPPs (aka "SPP") and how delays caused by such a technique add to equipment damage and diminish the safety and reliability of the collection circuit with respect to arc flash, arc blast, temporary overvoltage, and incident energy. Second approach, it is discussed the operation of the grounding breaker in detail. The PSCAD and ETAP simulations were the tools used to support claims made concerning arc flash and remote transfer trip and to show where the grounding breaker overcomes such problems and provides superior protection compared with remote transfer trip.

Circuit breakers are mechanical switching devices that connect and break the current flowing in the circuit, which can be the nominal current or the fault current. Typical circuit breakers are composed of one switch that is either open or closed. Generally, some WPP or SPP only use non-grounding feeder circuit breakers as shown in Figure 1.

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In the collection circuit of a WPP or a SPP, a typical circuit breaker clears the affected feeder from the main station transformer (i.e., the transmission system) and the transmission system. However, such a design is limited and does not provide functionality, such as anti- islanding or temporary overvoltage mitigation.

Another special type of circuit breaker provides much more functionality and protection; this circuit breaker is called the grounding breaker [1], which requires only one signal from a relay to separate the collection feeder circuit from the main plant transformer. Then the interlocked switch grounds the collection circuit; the full process occurs in about three cycles from the initiation of a fault. With the impedance of the collection circuit (approximately 1/15$^{th}$ of the impedance of an individual wind turbine transformer) and with all three phases effectively bolted to ground, the voltage on the separated feeder quickly collapses.

The grounding breaker shown in Figure 2 is designed for the feeder collection circuits of WPPs and SPPs. The line side of the circuit breaker is composed of vacuum interrupters and bushings to connect to the 34.5 kV collection circuit. For information concerning the operation and ratings of vacuum interrupters, see [7] and [8]. The grounding circuit when closed connects the generator's side of the feeder collection circuit to ground. The grounding breaker within WPPs and SPPs connects between the substation bus and the wind turbines or solar inverters as shown in the single line in Figure 3.

As shown in Figure 4, the GROUNDING BREAKER is closed and the grounding switch is open as indicated by the red outline illustrating a path for the flow of current. When the breaker is commanded to open by the relay, both sets of interlocked vacuum interrupters operate. The line side opens first, and then the ground side closes as shown in Figure 5. The interlocked grounding switch automatically switches the collection circuits to ground immediately after the clearing the fault and the feeder from the plant. As a result, improved anti-island functionality, superior TOV protection, and less incident energy into an arc flash or arc blast are provided.

In WPPs and SPPs, conventional breakers open and disconnect the affected feeder from the transmission system and then allow the delta connected collection circuit to operate without a ground reference.

The grounding breaker, however, provides a better ground reference than a circuit breaker and opens with an electrical switching time of 4–12 ms, or less than one cycle, thus meeting the temporary overvoltage requirements for lighting arrestors.

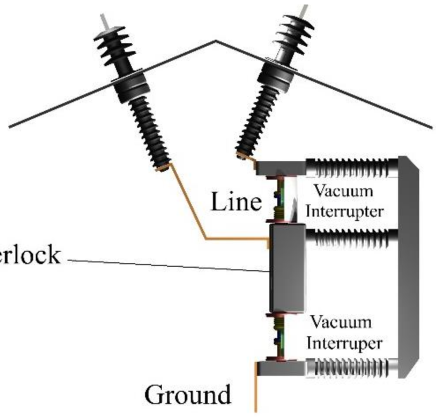


Fig. 2: Grounding Breaker (circuit breaker combined with a grounding switch) operates with one trip signal.

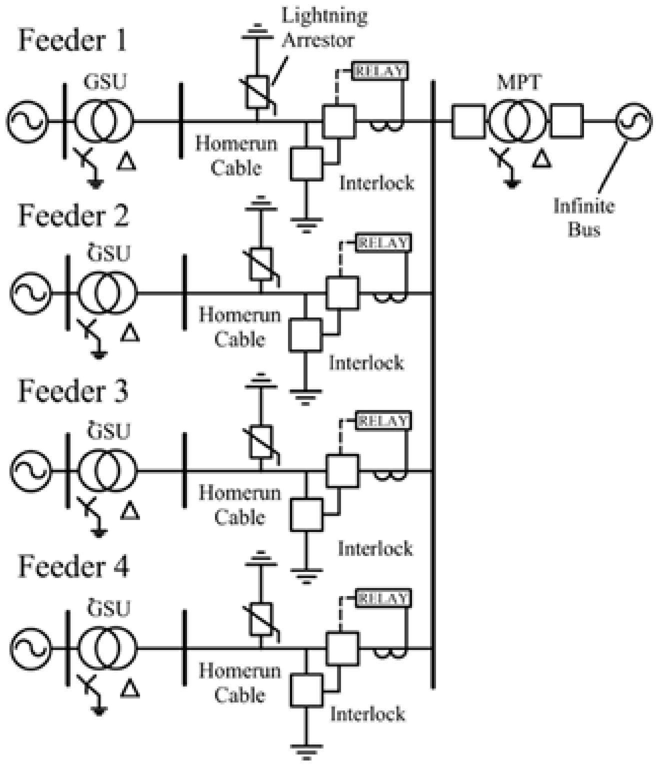


Fig. 3: WPP or SPP with Grounding Breaker Providing Protection at Each Feeder Circuit.

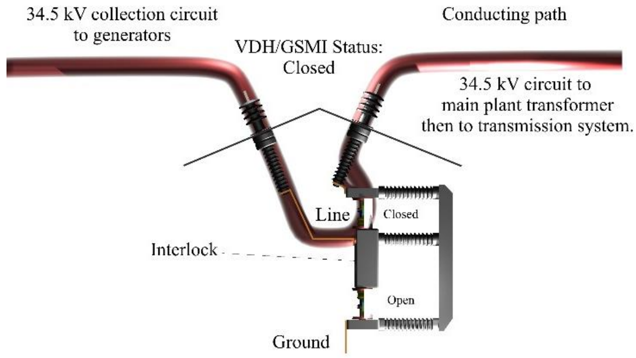


Fig. 4: Grounding Breaker in Closed Status.

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PSCAD simulations shows that remote transfer trip for WPPs and SPPs and how delays caused by such a technique create TOV, more damage to equipment, less revenue, puts personnel's health and safety at risk through lethal arc blast situations. It also shows that the grounding breaker overcomes such problems to provide superior protection compared to it.

The under the simulations conditions, the grounding breaker constitutes a best practice concerning operation and protection of personnel and equipment that work with collection feeder circuits within WPPs and SPPs.

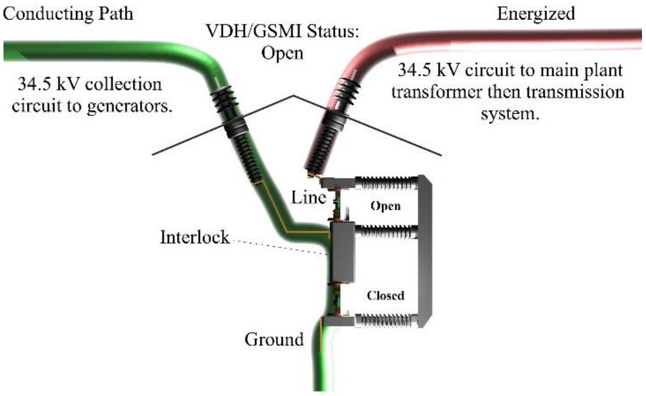


Fig. 5: Grounding Breaker in Open Status.

## 2. Remote Trip

TOV according to IEEE 1313.1-1996 in part means, "an oscillatory phase to ground or phase to phase overvoltage that is at a given location of relatively long duration in seconds or minutes and that is undamped or weakly damped."

TOV limits peak voltage such as that specified for surge arrestors, where such limits are found expressed as maximum continuous operating voltage (MCOV) in per-unit values for the root-mean-square (RMS) waveforms.

According to the California Public Utilities Commission, transfer trip means "the opening of a circuit breaker or recloser from a remote location by means of a signal over a communication channel such as microwave, power line carrier, radio, or, most likely for devices at the distribution level, a leased telephone line" [3].

The opening of a wind turbine unit or solar inverter circuit breaker from a remote location with a signal over a communication channel, such as fiber, takes time to complete; this delay is called latency. Delays from the initiation of a fault on the collection circuit to the time when the equipment is separated or isolated from the fault is called the clearing time (IEEE Standard 551). WPPs and SPPs are made up of individual collector circuits. When protecting a collection circuit, there are two objectives: clearing the fault from the individual generators and clearing the fault from the plant. For remote trip, it is focus on the timing of both.

As a solution, remote trip for WPPs or SPPs is a protection technique that has two options. In Option A, the feeder breaker is not delayed. The fault is cleared from the plant first and then from the generators. In Option B, the feeder breaker is delayed; therefore, the generators are cleared first and then the plant. Both techniques have dire consequences (see Figures 7, 8, and 9).

If Option A is chosen, the protection objective is to avoid or minimize the time personnel and equipment are exposed to the huge fault currents sourced from the transmission system. The feeder breaker operates first and clears the fault from plant. As a result, the engineers limit and reduce the incident energy and 15,000 amps of current sourced from the transmission system. However, TOV is now a problem.

If Option B is chosen, the protection objective is to avoid temporary overvoltage on the collection circuits. The generators are shut down first and the fault cleared. Then the feeder breaker opens, and the fault is cleared. However, now incident energy is now a problem.

In Option A and also in Option B, for a WPP or a SPP, a relay sends a remote trip with two signals, one to the generators and one to the feeder breaker. The signal to the generators is over a communication line, such as fiber, and runs from the substation (i.e., a remote location) over the fiber communication medium to each individual generator. A trip signal is sent to open the breaker of each generator and/or perform a soft shutdown during a fault.

However, both options have consequences. Figure 6 shows two collection circuits, one with a grounding transformer and one without. When the collection circuit is separate from the plant and the transmission system, the circuit's conductors are delta configured; consequently, the impedance to ground is very high. When the feeder breaker opens, energy supplied to the feeder by the generators (which are on-line and producing power) causes the voltage to increase in the separate collection circuit.

TOV occurs because the remote signal gets to the generators late. The delay is called latency. In a vain attempt to fix the problem of TOV, a grounding transformer is introduced to provide a lower impedance to ground, when the delta configured collection circuit separates. As the grounding transformer cannot pass active power during severe islanding, the transformer still has an excessive voltage increase; consequently, a grounding transformer is not found to solve the problem of temporary overvoltage.

The problem of TOV lies in the fact the generators are not shut down because of latency. Figure 7 shows some of the causes of latency, such as switches, fiber cables (or radio), the control system, and equipment. Standards identify the typical latencies one should expect when sending a signal for equipment to operate. IEC 61850 is a contemporary standard concerning the configuration of devices for electrical substation automation systems. This standard provides methods that allow different components to communicate with each other. Such protocols can run over TCP/IP networks or substation local area networks (LANs) using high-speed switched Ethernet to obtain the necessary response times of less than 4 ms for protective

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relaying.

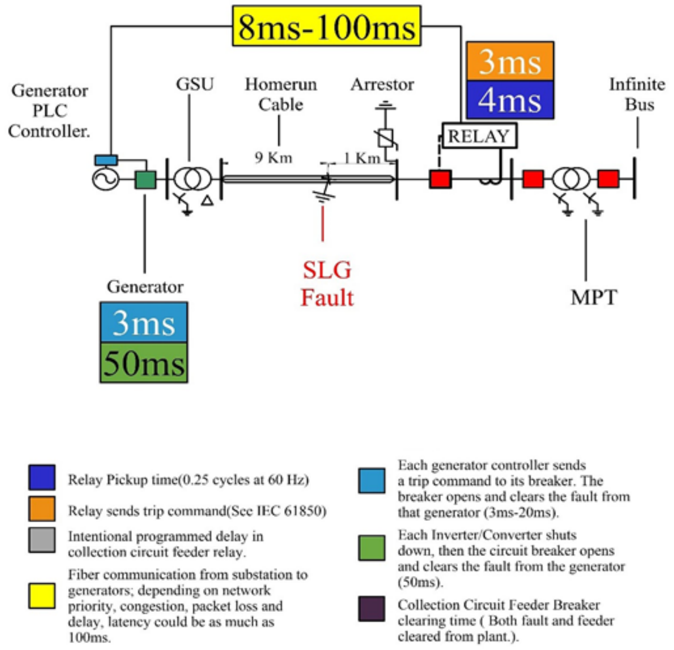


Fig. 6: Collection Circuit and Remote Transfer Trip.

In addition to latency, Table 1 lists the failure modes, which prevent the message from getting to the equipment. If such failure modes are not present and the message gets to the right device, then the typical latency times for remote trip introduce delays; they are shown in Table 2 [4]. In addition, [5] presents that feeder clearing times can exceed 122 ms when remote trip is used. Figures 7, 8, and 9 and Table 3 show that both techniques (delaying feeder breaker clearing or no delay in feeder breaker clearing) have consequences.

| Remote Trip Causes of Substation Communication Failure | |
|---|---|
| Item | Causes |
| 1 | Processor Power Supply Failure |
| 2 | Cyber Intrusion |
| 3 | Firmware Upgrades |
| 4 | Data Path Reconfiguration |
| 5 | Fiber Optic Cable/Damage Radio Failure |
| 6 | Bandwidth Saturation |

Table 1: Causes of Remote Transfer Trip Communication Failure

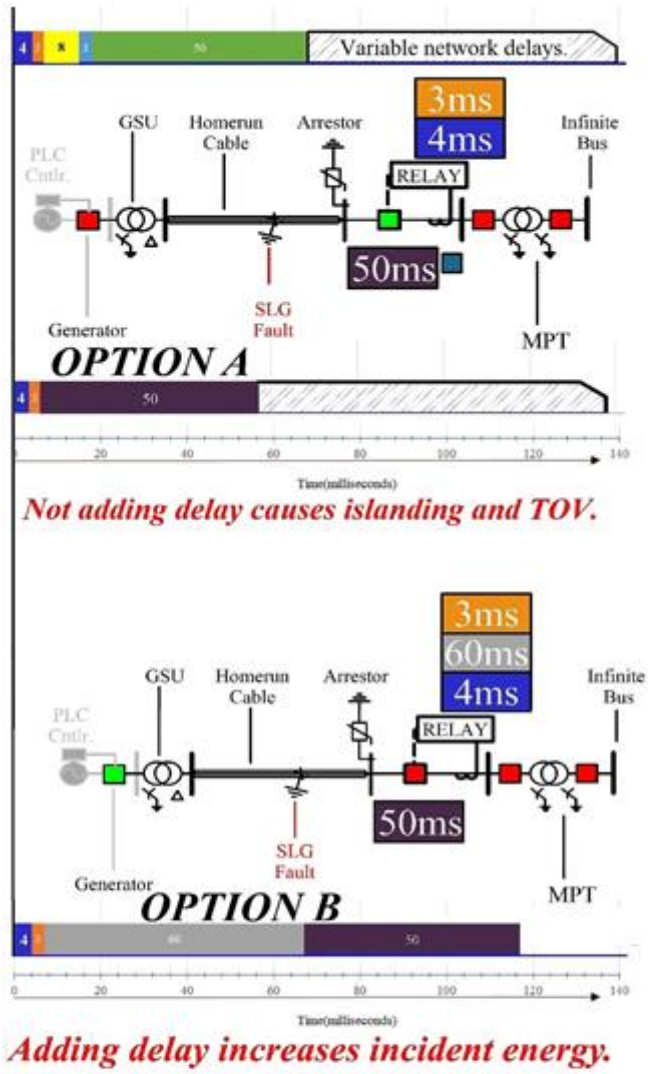


Fig. 7: Option A (TOV) or Option B (Incident Energy).

## 3. SURGE ARRESTORS AND TEMPORARY OVERVOLTAGE (TOV)

Surge arrestors come with a given temporary overvoltage curve called a duty curve which can be found on a graph supplied by the manufacturer that shows the (50–60 Hz) withstand voltage vs. time for arresters. The time is usually given from 0.01 s to 100,000 s in RMS values in a per-unit rating. The duty curve and the prior duty curve should be higher than the continuous operating voltage of the collection circuit.

The prior duty curve is lower in per-unit voltage than the duty curve and represents that the surge arrestor can be repeatedly subjected to RMS voltages below that value and the arrestor will continue to perform according to the manufacturer's specification. When the voltage exceeds the prior duty curve, the arrestor is damaged, and its current voltage ( I-V ) characteristic changes. Therefore, when the I-V characteristic is lost, the insulation coordination study

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for the collection circuit is no longer valid, and the entire plant is now at risk.

Without a surge arrestor on the collection circuit, the voltage increase would exceed the insulation capabilities of the collection circuit components. When a feeder breaker, which cannot ground the collection circuit, clears the fault (on that collection circuit) from the plant and the transmission system while the generators are producing power, the voltage quickly escalates along with the current through the prior duty curve of the lighting arrestor. When a feeder is separate from the plant, PSCAD simulations with the generators still running show the TOV prior duty curve is typically exceeded regardless of the I-V characteristic used, due to the energy supplied to the collection circuit.

## 4. Remote Trip and Avoiding Incident Energy

When avoiding incident energy and using Option A, the relay clears the fault from the plant by opening the feeder breaker first. The relay is located at the substation, and the generators are 5 to 10 miles away. As generators are shutdown second as opposed to the breaker being opened first, the incident energy is far less; however, the TOV results in damage to the surge arrestors and then a change in their I- V characteristic [14], which then damages other equipment. Figure 7 shows the timing diagram with Tables 1, 2, and 3 in mind, and Figure 8 shows the delays that occur when communication problems appear in the network.

When avoiding incident energy and enduring TOV (e.g., Option A), the relay clears the generators before the relay clears the feeder breaker. The relay is located at the substation, and the generators are 5 to 10 miles away. As the generators are shut down first before the feeder breaker opens, the delay allows the incident energy to build in the fault; consequently, damage to equipment is more severe, and the fault can be fatal to personnel (see section (043) and Table 4).

Remote trip techniques must be coordinated to protect the equipment within the plant. However, although relays are fast, they do not process information instantaneously. Time delays are always introduced in digital processing and communication equipment (see Figures 7, 8, and 9). When using remote trip, one must keep latency in mind.

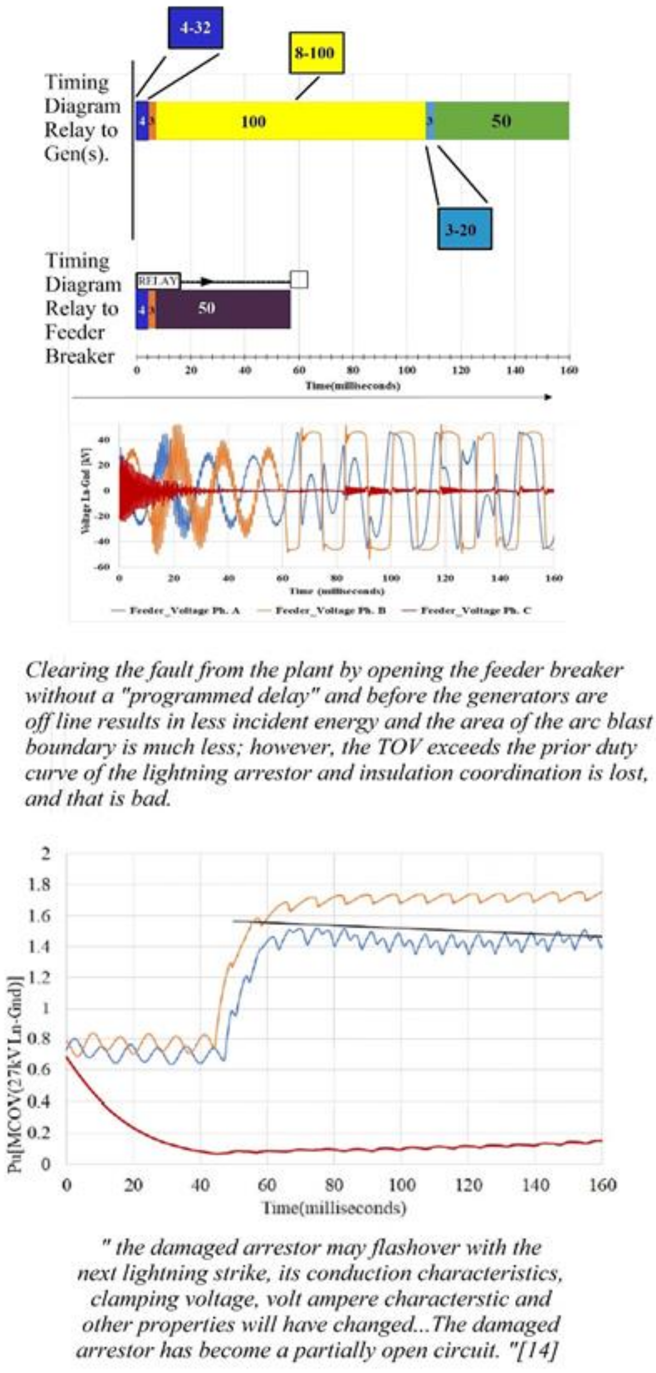


Fig. 8: PSCAD Simulation **Option A**, Remote Trip, and TOV.

Regarding latency, Tables 2 and 3 and Figures 7, 8, and 9 show the latency of the two signal paths where an engineer may add up the signal propagation delays from the substation to the generator. The process begins with the initiation of the fault through the sensing current transformer to the clearing of the fault. The figures start with a relay pickup time of 4 ms and a delay of 3 ms to issue the trip command. From there, the trip command has two paths, one to the feeder breaker and one to the generators.

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| Causes of Latency | | |
|---|---|---|
| Item | Device Operating Time | Time (ms) |
| 1 | Input debounce | 2 |
| 2 | Processors | 4 |
| 3 | IEC Message 61850 | 8–100 |
| 4 | Misc. updates | 4 |
| 5 | Communication | 4–32 |
| 6 | SPP or WPP Breaker | 50+ |

Table 2: Causes of Latency

If one includes a radio with a latency of 32 ms (net change 24 ms), the total latency with Table 2 in mind is between 72 ms and 146 ms. With such delays included with collection circuit feeder breaker operation, what are the consequences regarding TOV? Two scenarios: The breaker is delayed from opening, and the generators are shut down first. If the breaker is not delayed from opening, and the generators are shut down second. What happens with arc flash and arc blast as they relate to incident energy and TOV?

## 5. Remote Trip and Incident

## Energy

Option B introduces incident energy by opening the feeder breaker with a programmed delay, which results in little or no temporary overvoltage. For example, a WPP or a SPP, with a 230 kV to 34.5 kV main substation transformer, which is rated at 90 MVA with 8% impedance, is connected to the transmission system at the point of interconnection. The main plant transformer is Y connected and grounded on the 34.5 kV side. The main plant transformer is connected to a very strong transmission system, and the main station transformer is capable of sourcing 18,000 amps peak on the home run feeder cable, which has a faulted single line to ground. In addition, the other feeders may source between 750 and 1000 amps in the same fault. The longer the feeder breaker is closed, the more time 1800 amps feeds the fault.

Concerning incident energy and remote trip, the arc time and the resulting damage to equipment and injury to personnel are important to consider. Section 70E by the National Fire Protection Association describes procedures for arc flash studies. In this report, ETAP to calculate the incident energy due to arc flash is used.

Concerning arc flashes and remote trip, to protect the equipment on the feeder from temporary overvoltage, a delay is programmed into the feeder relay, which prevents the feeder breaker from opening for at least 117 ms or seven cycles from the start of the fault which exceeds 24 cal/cm$^2$ at a working distance of 36 in. When considering arc flashes, the increase in arc time is significant and adds to the risks personnel already take when working on such equipment.

Adding to the arc blast, the generators on the feeder collection circuit can also contribute energy while the fault is occurring. The generator’s current can be added to the fault current sourced through the main plant transformer to the fault location. When the circuit breaker clears the plant from the fault and interrupts the current, generators are still feeding the fault. Figure 9 clearly shows that as the best case faults can persist for as little as seven cycles. If the fault lasts longer, Table 3 shows at 36 inches after 200 ms the incident exceeds 40 cal/cm$^2$, which is lethal.

Because remote trip techniques allow for an increased arc time, arc flash, and arc blast, faults become increasingly dangerous due to the added incident energy. An ETAP model of a representative wind farm shows a fault on the transformer where personnel are present and are within the arc flash boundary. The arcing fault current in the ETAP model was approximately 12,000 amps RMS for between 3, 6, and 12 cycles. The results of the model are shown in Table 4.

According to NFPA 70E, annex K issued by the Virginia Division of Mineral Mining, concerning arc flash and blast even with proper personal protective equipment (PPE), severe injury may result from heat from the arc flash, and the resulting force of the pressure wave and shrapnel is lethal [6]. Therefore, it is imperative that the incident energy is minimized.

Concerning remote trip, minimizing incident energy from the transmission system may result in TOV.

Figures 7 and 8 show a timing diagram where the two signals race to the generators and the feeder breaker. In Figure 7, the signal is delayed to the feeder breaker and allows more incident energy. Figure 8 shows the trip signal to the feeder breaker is not delayed; however, the variable latency present in both techniques suggests there is a likelihood of temporary overvoltage and islanding.

| Remote/Trip Relay Coordination and Latency (Option B) See IEC and Ref [5] | | | |
|---|---|---|---|
| Item | Device | Remote Path (ms) | Breaker Path (ms) |
| 1 | Feeder Ground Fault | 0 | 0 |
| 2 | Feeder-Relay Pickup (1/4 cycle to 32 ms; see Ref. [5]) | 4–32 | 4–32 |
| 3 | Relay Programmed Delay | x | 11–120 PSCAD (60) |
| 4 | Relay processor time | 3 | 3 |
| 5 | Relay-Trip Signal Transport Lag (IEC 61850) [12], [13] | 8–100 | x |
| 6 | Wind Turbine Controller | 3–20 | |
| 7 | WTG Breaker Opens | 50 | X |
| 8 | WTG Clearing Time | 68–205 PSCAD (160) | X |
| 9 | Feeder Breaker Opens | X | 50 |
| 10 | Feeder Clearing Time | X | 68–205 PSCAD (117) |

Table 3: Remote Trip, Relay Coordination, and Latency. Note: At 60-ms delay, incident energy exceeds 24 cal/cm$^2$ at a working distance of 36 inches. See Table 4.

## 6. Remote Trip in Summary

Figures 7, 8, and 9 and Tables 1, 2, and 3 show that either way there are dire consequences with remote trip when applied to WPPs and SPPs. Remote trip either delays the opening of the collection circuit feeder breaker and adds to the incident energy in the fault or opens the feeder breaker too soon and causes temporary overvoltage. Energy from the overvoltage rapidly consumes the useful life of the surge arrestors or changes the I-V characteristic, such that the U.S. Nuclear Regulatory Commission states “the damaged arrestor has become a partially opened circuit” [14].

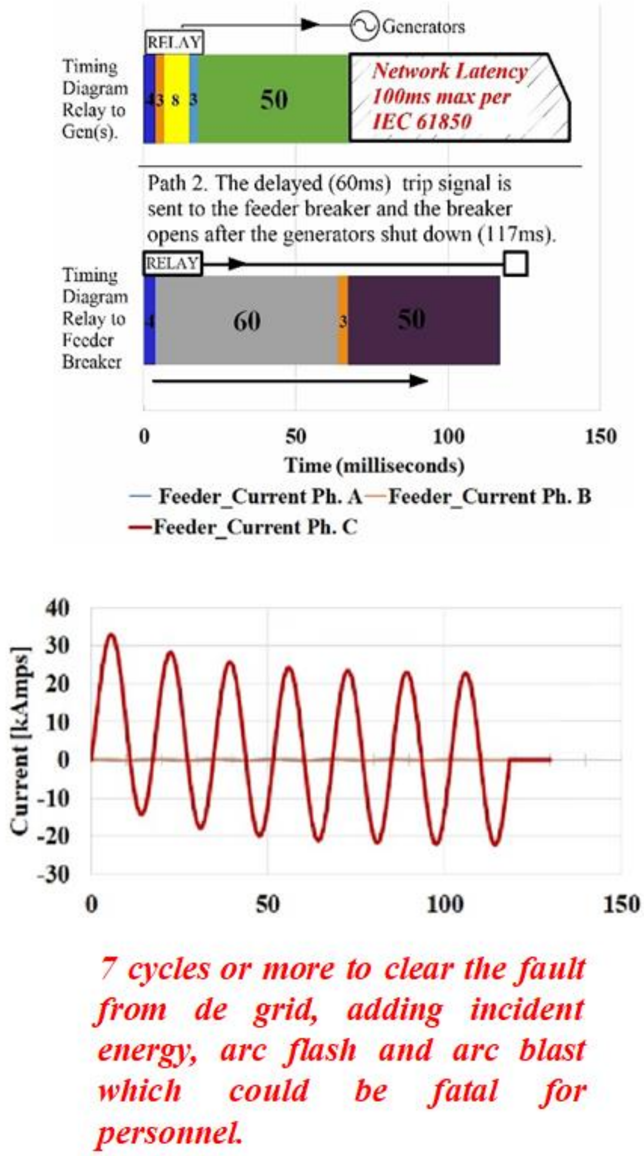


Fig. 9: PSCAD Simulation Option B Incident Energy (See Table 4).

One could presume that the insulation coordination is lost. Unfortunately, several causes of variable latency prevent wind turbines or solar inverters from getting the command at the right time or all the time from the relay connected to the feeder circuit breaker; whereas the resulting latency prevents the wind turbines or solar inverters from shutting down before the feeder breaker opens. When considering incident energy and assuming the relay does not require a handshake (e.g., acknowledgment of the action), the time to disconnect the affected feeder from the transmission system can exceed 100 ms or even 200 ms. Concerning safety, 100 ms to 100 ms at 36 inches away from a fault sourced from the transmission system will exceed the incident energy of 40 cal/cm2 and can be fatal to personnel.

| Incident Energy and Injury |
|---|

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| Item | Duration (ms) | Working Distance (in) | Incident Energy (cal/cm$^2$) |
|---|---|---|---|
| 1 | 50 | 36 | 12 |
| 2 | 100 | 36 | 24 |
| 3 | 200 | 36 | 43 |

Table 4: Arc Blast/Flash Incident Energy

Because of the resulting arc flash and arc blast (even with proper PPE), severe injury may result from 1) heat from the arc flash, 2) the force of the pressure wave, and 3) shrapnel. Therefore, it is imperative that the incident energy be minimized. When it comes to remote trip, and with the above in mind, relay engineers cannot coordinate the relay for both cases without giving up some degree of protection. If they delay, they add incident energy and injure personnel. If they do not delay, they risk temporary overvoltage that can destroy equipment on the feeder. Therefore, one must keep in mind that delays and failure risks are associated with this technique.

There are devices that remote trip could be used in conjunction with; for example, the combined interlocked breaker grounding switch (GROUNDING BREAKER) is a device that can reduce the incident energy. The GROUNDING BREAKER does not require such delays and has been shown to keep TOV below the prior duty curve of a surge arrestor (see Figure 9). The GROUNDING BREAKER provides a very low impedance path to ground, can clear a fault within 3.5 cycles or 50 ms, and coordinates well with generators and surge arrestors on the feeder circuit.

## 7. Conclusion

When it comes to protecting a WPP or a SPP, the GROUNDING BREAKER is essential. Damage due to faults on collection circuits happen fast. Reports indicate remote transfer trip techniques can introduce a delay of more than 122 ms, and references indicate that the delay can be as long as 205 ms (Table 3) and are not 100% reliable. Although all faults create damage, remote trip delays disconnection from the transmission system and consequently allows high-magnitude fault currents sourced from the transmission system to persist.

A GROUNDING BREAKER if properly coordinated can separate the affected feeder from the transmission system and WPP or SPP within 3.5 cycles. This is less than half the time of a remote trip and guarantees the feeder has a great ground reference. If the remote trip is not operating, the generators may island. In addition, temporary overvoltages can occur and persist for longer periods of time on the feeder collection circuit.

Table 1 shows the likelihood that the transfer trip signal will not (emphasis added) reach all the wind turbines or solar inverters 100% of the time is a near certainty. Although protection schemes may race the signals to the generators and feeder breakers to trip both simultaneously, Table 2 and Table 3 show the delay is long enough to significantly add to the incident energy, where the GROUNDING BREAKER limits it. In addition, if a disruption to communication occurs, there will be units on- line when the line breaker opens; consequently, temporary overvoltage and damage to equipment are very likely to occur.

| Comparing Remote Trip to Grounding Breaker | | |
|---|---|---|
| **Topic** | **Remote Trip** | **Grounding Breaker** |
| Incident Energy | Greater than 40 cal/cm2 at 36 in (lethal) @ 200 ms. | Less than 24 cal/cm2 at 36 in. |
| Temporary Overvoltage | Delayed message causes TOV and loss of insulation coordination. | Prevents TOV and maintains insulation coordination. |
| Lightning Arrestors | TOV will change the I- V characteristic and collection circuit will not be protected. | Voltage remains below prior duty curve; equipment is better protected. |
| Generator step up transformer | TOV and loss of insulation coordination will damage the transformer. | Voltage remains below prior duty curve; equipment is better protected |
| Dangers to personnel | Blast from 40 cal/cm2 is lethal. | At 24 cal/cm2 PPE is available. |
| Islanding | Trip signal does not get to the generators in time; they produce power into an open circuit causing TOV which damages equipment. | Grounds the home run cable of the collection circuit providing a very low impedance for the generators to produce. |
| Grounding Transformer | Ineffective at preventing TOV. | Grounding breaker either eliminates the need or complements existing installations and improves protection. |
| Under Voltage Ride Through | Delayed or unreliable trip signal TOV is present, and ride through could cause islanding. | Collapses voltage in most cases below 15%. |

Table 6: Comparison, Remote Trip vs. Grounding Breaker.

A GROUNDING BREAKER once grounded will create a bolted three- phase ground on the home run cable. This, in turn, will create an impedance on the home run cable of less than 2 ohms as seen from the junction box to the GROUNDING BREAKER for a 1000 MCM cable that is 10 km long. Comparing the home run cable impedance to that of the generator step-up transformer impedance, which is j28 ohms at 34.5 kV, the ratio is approximately 15 to 1.

With the home run cable grounded by the GROUNDING BREAKER, and even with some semblance of proper operation on the three-phase grounded feeder, each generator limits the current to a maximum magnitude during

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the fault of approximately 42 amps at 34.5 kV, and the voltage rise across the generator step-up transformer is less than 1.1 kV.

The maximum current (amps) magnitude for all 12, 2 MW generators during the fault, which are current limiting, is approximately 500 amps, and the resulting voltage increases across the home run cable at j2 ohms is less than 1 kV. Consequently, each generator is hard-pressed to keep its AC mains voltage above 10% with the GROUNDING BREAKER creating a bolted three-phase ground on the home run cable.

At that point, each generator should trip offline, and islanding should not occur. In addition, and as an aside and with the above in mind, each generator should coordinate well with low-voltage ride-through requirements.

In this paper, a sequence of events and an operational overview concerning the GROUNDING BREAKER for WPPs and SPPs are presented. With the GROUNDING BREAKER in mind, the following conclusions are shown:

1. The GROUNDING BREAKER operates two vacuum interrupters with an interlock; therefore, the GROUNDING BREAKER operates with at least one trip signal.
2. There are three states with respect to impedances during the operation of the breaker.
3. In the GROUNDING BREAKER, the line interrupters open first, and the ground interrupters close second. With the GROUNDING BREAKER, a faulted feeder is disconnected from the transmission system first, and then the faulted feeder is bolted to ground.
4. The transition state of the GROUNDING BREAKER where both vacuum interrupters are open is from 4 to 12 ms.
5. The operation of a GROUNDING BREAKER demonstrates a clear change in impedance as the GROUNDING BREAKER operates. Generators can detect such a change and act on it.
6. The GROUNDING BREAKER when closed to ground results in a very low impedance of the home run cable to less than 2 ohms measured from a junction box (1000 MCM less than 10 km).
7. TOV duration is minimized by the combination of the fast transition state of the GROUNDING BREAKER and the surge arresters. Note, without a GROUNDING BREAKER, the arrestors can be destroyed by other protection schemes. After that, if the arrestor is not replaced, expensive collection circuit equipment is damaged thereafter.
8. A GROUNDING BREAKER significantly lowers the energy burden on surge arrestors, and engineers can easily coordinate.
9. The GROUNDING BREAKER provides a better reference to ground than a grounding transformer and consequently reduces the burden on surge arrestors.
10. Given the typical design variations of WPPs and SPPs and the generators with current limiting capability, the GROUNDING BREAKER should provide a very low impedance on the feeder circuit and cause the AC mains voltage at each generator to go below the minimum operating voltage and force them offline to prevent islanding. (See the low-voltage ride- through paper.)
11. With fewer modes of failure, the GROUNDING BREAKER is more reliable than remote transfer trip.

The PSCAD simulations show the GROUNDING BREAKER resolves issues of temporary overvoltage and incident energy, where delays are not needed to clear the fault from the plant. The GROUNDING BREAKER completely operates within nearly 50 ms to separate the affected collection circuit and ground it, so it collapses the voltage. The GROUNDING BREAKER relieves the surge arrestor and keeps the resulting TOV below the prior duty curves. As a result, it is concluded that the use of the GROUNDING BREAKER in the design and construction of generating projects, such as WPPs and SPPs, constitutes a best practice.

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