A Review of Intertie Protection

Terrence Smith
Commercial Application Director
GE Grid Solutions
.

George Pitts
Reliability Engineer
Tennessee Valley Authority

Abstract – **Many industrial facilities will have on site generation and it is important that the facility design its protection and control system to protect the interconnection between the facility and the utility supply. This paper is a tutorial on the protection necessary to protect the utility from issues within the industrial facility and to protect the facility from issues on the utility supply. Topics to be discussed will include: directional power elements, directional overcurrent elements, load shed schemes and contingency schemes, and utility reclosing schemes.**

Introduction

Many industrial facilities have on-site generation and a utility tie. The combination of these two sources provides the energy needs of the facility. Protecting the industrial facility from issues on the utility system as well as protecting the utility from issues on the industrial system poses some unique challenges. IEEE 1547, describes some of the protection necessary to properly intertie the industrial facility and the utility but an understanding of the protection and consequences is necessary to properly protect both the facility and utility. If the utility system has a fault, the facility generation can feed that fault so protection must be provided by the facility to separate in the event of a utility fault. Likewise, a fault in the facility will be fed from the utility so a separation is necessary if the fault isn't cleared inside the facility. Additionally, if the utility loses its source the facility will feed all of the utility load and will cause a collapse of the facility system.

Once a separation between the utility and facility has occurred, additional protection and control schemes must be used to maintain the facility and to allow a smooth restore of the utility to the facility. For example, if the facilities on site generation is not sufficient to feed the entire facility the facility will need to shed loads so that the onsite generation capabilities match the load, otherwise the facility power system will collapse.

When the utility feed into the facility is restored, care must be taken so that the facility system is synchronized to the utility system prior to restoration, which requires a synch check control system. Additionally, the reclose scheme of the utility must account for the fact that facility may take longer to clear a fault than the utility scheme.

I. Directional Protection for Utility Faults

When a fault is initiated on the utility system, that fault can be feed from the facilities on site generation. If the facility does not separate from the utility to clear the fault it will cause frequency collapse of the facility system. Figure 1 shows this type of collapse. In this case the facility only had over-current protection without a directional over-current for the transformer that connects to the utility. The utility system had a fault and the utility successfully cleared the fault. The fault current fed by the facility was less than the pick-up of the transformer over-current, so the overcurrent on the transformer did not operate to clear the fault. The facility continued to feed fault current from its generator. The generator prime mover could not supply the power of the fault so the generator began to slow down. Over the course of 2.5 seconds the frequency of the generator dropped from 59.95 Hz to 54.5 Hz. The generator was ultimately tripped on under frequency. The generator had two under-frequency elements, one was set sensitive with a long delay and the other was set less sensitive with a shorter delay. The second under-frequency element tripped and was set to 57 Hz with a 1 second delay. While the element was timing the frequency continued to decay and ultimately decayed to 54 Hz before the generator was tripped off-line.

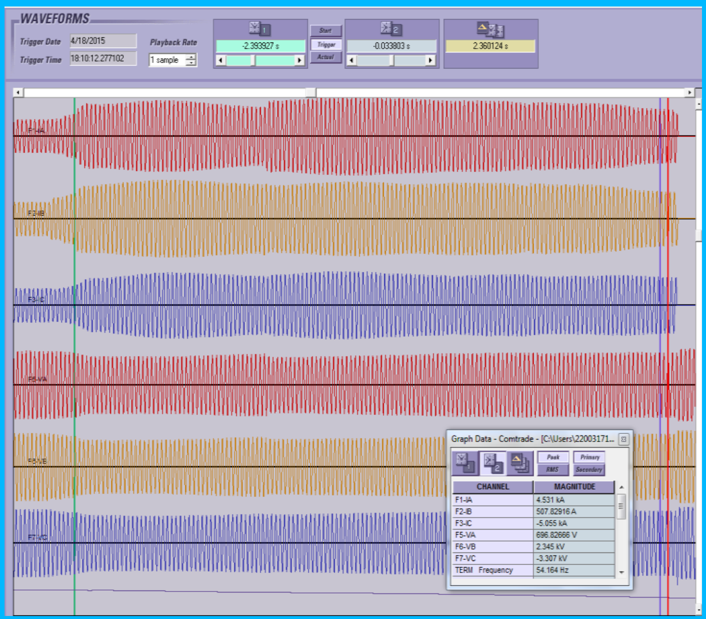

Figure 1 – Generator UF Trip

This underfreqeuncy event caused the entire facility to be in outage. The more desirable scenario would be to have tripped the inter-tie transformers high side breaker, separating the facility from the utility. In that situation the facility could have shed loads to achieve balance and continued to run on its onsite generation. The element that would have prevented this operation would have been a directional over-current with a tripping direction toward the utility. The over-current element on the transformer was a non-directional element, meaning it could operate in either direction, but the fault current being provided by the facility generator was less than full load amps on the generator, so the non-directional element did not trip. The phase directional element could have been set with a tripping element toward the utility and a more sensitive setting. That element would have operated and cleared that fault, separating the facility and the utility.

The forward direction and reverse direction to the relay would be relative to the wiring of the relay current transformers and voltage transformer. If power is flowing into the facility and the relay has voltages and current wired correctly we would expect the phase angles between the voltages and current to be equal to the power factor angle of the facility. This would make the facility in the forward direction. This concept is demonstrated in Fig 2 below.

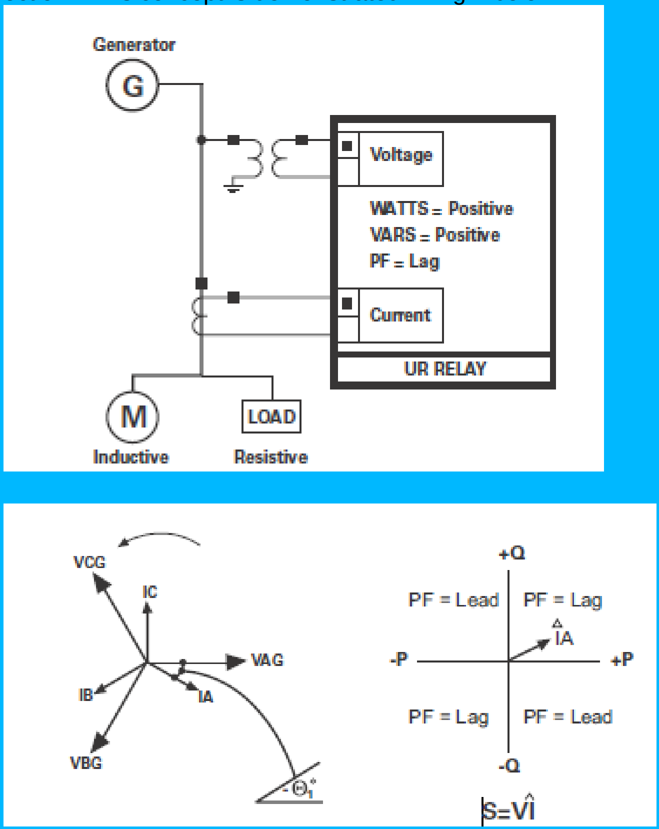

Figure 2 – Power Flow Conventions

A phase directional overcurrent characteristic is shown in figure three. A phase directional element uses a polarizing quantity to compare the operate quantity to, to determine direction. If is very important that the polarizing quantity angle be steady during the fault and not have shift associated with the fault. For that reason voltage is usually used for the polarizing quantity. For the phase directional element shown in figure two, the polarizing quantity for the “A” phase element is Vbc. Ground directional overcurrents are similar, except the operate current is typically neutral current and the polarizing quantity is either measured ground current or zero-sequence voltage. In either case, the directional element should be set to block an overcurrent element in the non-tripping direction. In this case, the forward direction for the relay was toward the utility. The desired application would have been to set a sensitive phase and neutral overcurrent that would be blocked in the forward direction. When the fault occurred in the reverse direction this element could have tripped to separate the utility and facility.

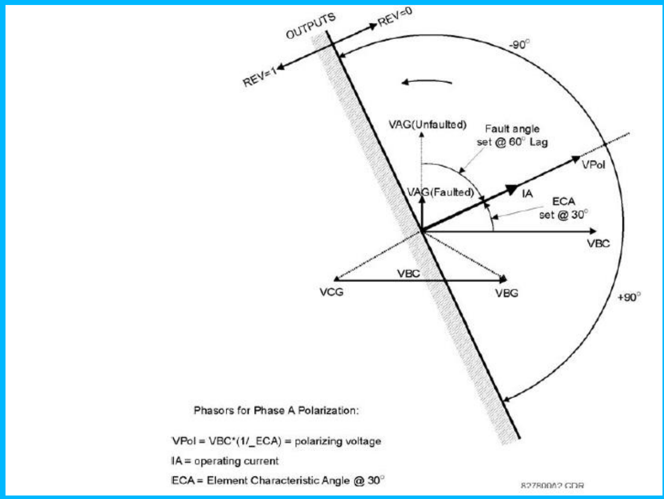

Figure 3 – Phase Directional Characteristic

II. Under Frequency Protection

In the case study from the previous example the facilities on site generator could not supply the load of the utility fault current. This caused the facility generator to “slow” down and result in an under frequency trip of the generator. Under-frequency protection of the generator is essential since generator damage will result an under-frequency event. . These type of under-frequency events can result from a system wide disturbance or from a fault condition as in the previous example. In either case, it is more desirable to separate from the utility than to lose the generators for the facility. For that reason, under-frequency protection on the utility inter-tie should coordinate with the facilities’ generator under-frequency. Essentially, the relay on the intertie should trip before the generator protection so that the facility can successfully separate from the utility in the event of a system wide under-frequency event.

III. Directional Power Protection

If, during a system event, the utility were to separate into discreet islands, the facilities could be separated into an electrical island where it’s generator is the only source on the island. If the facility did not have sufficient generation capability to feed that load it would start an under-frequency event described above. Additionally, if the inter-tie transformer or inter-tie buses are not rated for the load it is possible to over-load that equipment during the island condition. As seen in the case study, under-frequency events can be slow to develop, which means that they can be set with a relatively longer delay than other protection. In the case of the island condition it is undesirable to wait for the under-frequency elements to separate the utility from the facility since the facilities equipment will be “over-power” during the time delay and suffer from an off-nominal frequency. For this reason the facility should employ directional power protection to prevent excessive export of power into the utility system. The directional power element is similar to a directional over-current, but will operate from power settings rather than current. This means that voltage and current must be wired to the relay for the power and directional decision. The directional power element could operate for utility faults, but that protection is the directional overcurrent's role, since the overcurrent can operate faster. The directional power element is meant to operate when the facility is exporting more power than desirable.

The directional power element has direction as shown in figure two above. At a minimum, the directional power element should be set to trip and separate the utility and facility below the inter-tie equipment (transformer, bus, cables, etc) ratings. Additionally, the facility and utility should agree to the maximum amount of power that the facility would export and the directional power element should be set to trip before that power quantity is reached.

When choosing a protective relay to provide the directional power element, it is important to understand the sensitivity of the relay and the utility requirements. If a facility interconnects that is only intended to provide onsite power with no export capabilities, the directional power element should be set as sensitive as possible. Additionally, the utility may give the facility a requirement for very sensitive directional power that not all relays are capable of meeting. For these reasons the minimum sensitivity of the relay should be checked to insure that it meets the utility requirements at an import power only facility. For this type of facility a better type of protection may be a minimum forward power element. The minimum forward power element is shown in figure four below. The minimum forward power element operates when the power flow is in the reverse direction or when the forward power is below a setting. For an import only facility, the element could be set so that it tripped anytime the facility was exporting power to the utility or when the facility was importing power below a minimum settings value.

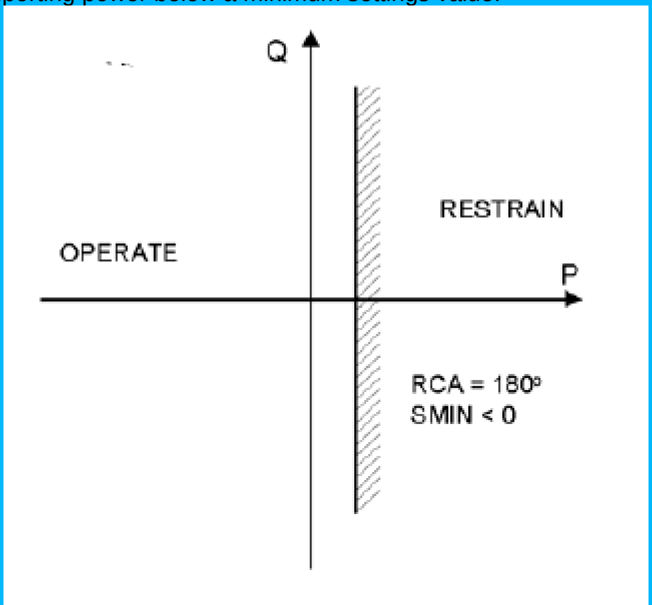

Figure 4 – Minimum Forward Power Element

IV. Generator Power Swing Protection

A stable power swing can is a condition where the system loses synchronism for a short period of time with the neighboring system, and then later regains synchronism. In an unstable power swing condition the system would never regain synchronism. There are two reasons which can cause this type of power swing as follows: One of the systems, which lose a significant amount of generation, instantly becomes much weaker, but the load of the system remains constant. The other condition is if the system is already weak and the load suddenly increases substantially.

The generator can also pull out of synchronization during a fault event when a pole is slipped in the generator. This type event typically occurs during a sever fault which cause the torque on the generator to exceed the exciters ability to provide field and keep the rotor synchronized to the stator. The violent acceleration and de-acceleration of the pole slip can cause damage to the generator and prime mover.

Either of these conditions can be protected against with power swing or out of step protection. That protection element typically uses a distance characteristic with two to three characteristics. A three element characteristic is shown in five four below. The element typically will look for the impedance trajectory to enter an outer characteristic and then dwell there sometime before entering the inner characteristics. This is shown with the different arrows in figure four and each of these times represents a different time delay in the element. To determine the size of the characteristics and the dwell time, a system study must be performed. Typically, the industrial facility does not have access to the utility system to perform that study, which can make setting this protective element a challenge. It is recommended to work with the utility to develop these settings for power swing detection.

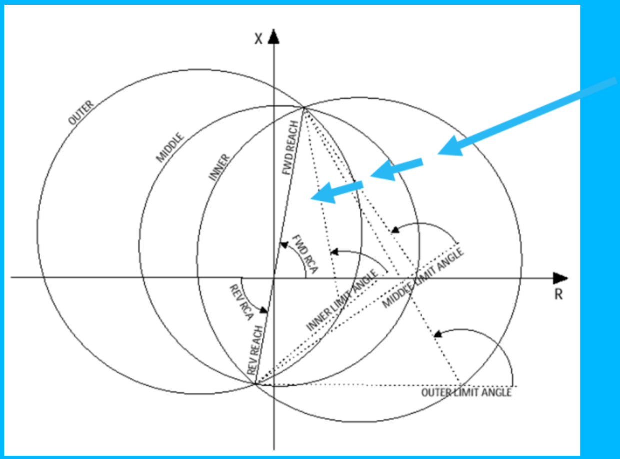

Figure 5 – Three Element Power Swing Characteristic

In the absence of input from the utility the facility can build a characteristic that has an outer characteristic of 1.5 times the transformer reactance and a reverse reach of 2 times the generator transient reactance. Binders could then be set to ½ the sum of the generator transient reactance plus the generator step up transformer reactance. This characteristic would insure that the impedance locus would pass through the GSU generator combination. In order to catch the characteristic and distinguish between a fault and a power swing, delay timers could be set so that the impedance trajectory would have to enter the outer characteristic and remain for 30ms, then enter the inter characteristic and remain for 50-100ms and then exit the inner characteristic and trip. This type of characteristic is shown in figure six below.

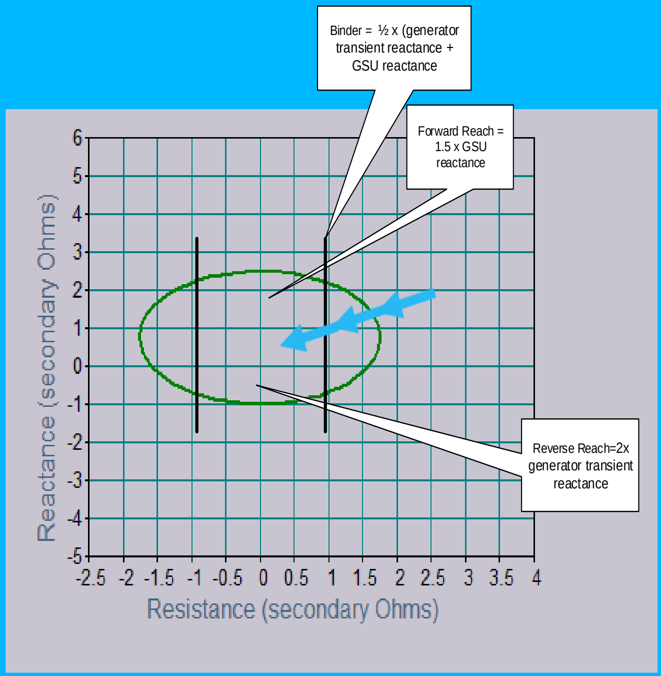

Figure 6 – Two Element Power Swing Characteristic with Blinders

V. Facility Load Shedding

Once the industrial facility has separated from the utility, if an imbalance exists between the facility load and generation, the frequency of the facility system will slow down as the generators begin to slow due to the excess load. As the frequency decays the generator efficiency is affected and the auxiliary loads may also be affected further exasperating the problem. In this situation, load must be removed or the decaying frequency can have a cascading effect and the entire facility power system can collapse. Several methods exist to recognize this condition and shed load before a complete power system collapse occurs. These load shed methods include: under-frequency, rate of change of frequency, under-voltage, and fast load shed.

In an under-frequency or under-voltage load shed scheme, relays are used to measure the frequency or voltage and when it has dropped below a setting for the desired time delay, non-essential load are shed in the attempt to bring the load balance back to a level the generator can supply. The issue around under-frequency or under-voltage load shed is that the frequency or voltage has already decayed to a low level before the relay can sense the condition. The quantity will continue to drop during the delay time of the element and the clearing time of the breakers with load to be dropped. It is possible with a high enough rate of frequency or voltage decay that the load will not be shed fast enough to preserve the system. Rate of frequency decay attempts to operate faster by operating on the rate of frequency decay rather than the frequency itself. A rate of frequency decay has a vulnerability that it may not operate for very slow rates of frequency decay. Additionally, it is very difficult for the facility to determine how fast its frequency will decay and the rate of frequency decay will be dependent on load conditions at the time of separation. An additional issue with both the rate of frequency change and under-frequency element is that both schemes remove pre-determined loads. During lightly loaded conditions, this means that the scheme will likely over-shed load, shedding more loads than necessary.

A fast load shed scheme is meant to remove excess loads before the frequency or voltage have taken a major deviation and to only shed the necessary load to preserve the system. In this scheme all the loads and sources are monitored in the system and sent to a load shed controller via a GOOSE analog message. The load shed controller will then know the reserve generation capabilities, existing generation, existing power from the utility and existing loads. When a contingency event, such as the opening of the utility breaker occurs, the controller can immediately calculate the difference between load, generation, and reserve generation and send a GOOSE trip command to non-essential loads. In this manner, the scheme can shed only the amount of non-essential load necessary preserve the system. Additionally, with this type of scheme the load can be shed in as little as 64ms, which is significantly shorter than an under-frequency event could be triggered [3].

VI. Utility Synch Check

A large portion of the faults on a transmission or distribution system are temporary in nature. These type of faults include animal's spanning the insulation, insulator tracking, and lighting arrestor failures. Utility transmission feeders are typically equipped with reclose control elements which will close the transmission line back after a temporary fault. Reclose increases the availability of a transmission line by automatically restoring the utility line once the fault has been cleared. In this case though, the utility and facility will become separated at a different location than the intertie breaker. While the two systems are separated from each other they may drift out of synchronism with each other and develop a difference in voltage, frequency, and or phase angle between the two systems. Reconnecting the two systems while they are out of synchronism with each other can cause damage to the facilities turbine or generator. For cases of faults on the utility system, the facility must insure that it's directional over-current protection will operate and clear the fault before the utility recloses back into the line. In order to insure that the directional protection has time to operate, the utility may have to disable its high-speed reclose and carefully coordinate the reclose dead-time so that the facilities directional elements have sufficient time to operate.

Additionally, the facility should supervise the close of the inter-tie breaker with a synch check element so that, when a separation occurs, the inter-tie breaker isn't allowed to close the tie between the facility and utility when they are out of synchronization. The synch check element will compare voltage, phase angle, and frequency between voltage transformers on the utility system and the facility system and only allow a close of the inter-tie breaker if those values are within acceptable ranges set in the relay.

VII. Conclusions

Care should be taken to insure that the intertie between the utility and the industrial facility is adequately protected. If the intertie is not properly designed and protected then the facility can face issues that needlessly cause the loss of the facility power system. While IEEE 1547 discusses this type of intertie protection, it is important to adequately understand the challenges and consequences of the protective functions. If the intertie isn't able to detect issues on the utility system and separate it can cause under-frequency or under-voltage events in the facility that can cause the loss of generation. Additionally, if the facility doesn't separate it could continue to feed a fault on the utility system.

Once separation has occurred, the facility should also insure that it has adequate generation capabilities to provide its own load. If not, the facility should have a load shed scheme to shed non-essential loads to preserve the facility power system.

.

References

[1] *IEEE Standard 1547.2-2008, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.*

[2] 850 Feeder Protection System, Instruction Manual, GE Publication GEK-119591E.

[3] Wester, C.; Smith, T.; Zhao, T; McGinn, D; Theron, J; Developments in Fast Load Shedding: IEEE PPIC Conference Record 2015

.

Biographies

Terrence Smith is the lead P&C Technical Application Engineer for GE Grid Solutions North American Commercial team. He has been with GE since 2008 supporting the Grid Solutions Protection and Control Portfolio. Prior to joining GE, Terrence has been with the Tennessee Valley Authority as a Principal Engineer and MESA Associates as Program Manager. He received his Bachelor of Science in Engineering majoring in Electrical Engineering from the University of Tennessee at Chattanooga in 1993 and is a professional Engineer registered in the state of Tennessee.

George Pitts is a Reliability Engineer in transmission operations with the Tennessee Valley Authority-TVA, in Chattanooga, TN. He has been with TVA since 2002 and also worked in system protection and analysis and transmission planning. Prior work included Pulp & Paper-Maintenance and Process Control; oil & gas pipeline engineering. He earned the BSEE degree from Mississippi State University in 1993 and is a professional engineer registered in the state of Tennessee.