Use of Import Underpower as a Means of Protecting Against Loss of Parallel Operation in DG Interconnection Applications

1.0 INTRODUCTION

This Application Note discusses the use of **import underpower** as a means of detecting, and protecting against, the *loss of utility parallel operation* in interconnected DG (distributed generation) applications. This protection is sometimes referred to as:

- Low Forward Power or Low Export Power from a utility perspective
- Low Reverse Power or Low Import Underpower from a DG perspective

For certain DG applications, such as peak-shaving, the interconnected utility may mandate that loss of parallel operation be detected by low power import by the DG from the utility.

Peak-shaving applications typically employ generation that cannot supply the given DG facility's total load. Therefore, some power import from the utility is always expected. This protection strategy is used in California ("Rule 21") to supplement undervoltage (27), overvoltage (59) and over/underfrequency (81O/U) protections that are typically used to detect loss of parallel operation with the utility (islanding).

As the number of DGs and load on a given feeder is dynamic, a situation may develop where a feeder is separated from the utility, and the aggregate power from all connected DGs equals the feeder's connected load. The 27, 59 and 81O/U elements may not be able to detect the loss of utility parallel operation in this scenario. The use of an import underpower element (32R-U) will succeed in detecting this potential islanding condition in peak-shaving applications, where the DG's facility minimum load exceeds the rating of its generators, and therefore a minimum power import from the utility is always expected.
This method is only applicable for non-export operations.

2.0 CONVENTIONS AT THE INTERTIE

To discuss the protection required, we must develop conventions on power import and export, as well as power flow conventions from the protective relay perspective. In applying Beckwith Electric's Intertie Relay models M-3410A and M-3520, with the CTs and VTs connected as shown in the three-line diagrams in Figures 1 and 2, the power flow convention for the relay is defined as *forward* with power being exported from the DG facility to the utility, and *reverse* with power being imported from the utility by the DG facility.

Figure 1 Three-Line Diagram for M-3410A illustrating Power Flow Conventions

Figure 2 Three-Line Diagram for M-3520 illustrating Power Flow Conventions

An import *underpower* element (from the DG's perspective) may be applied as a supplemental means of detecting loss of parallel operation with the utility, indicating the utility has opened the feeder circuit which supplies the DG facility. This concept is valid if it has been determined that the utility will always provide a minimum level of power to the DG facility, and if the power import by the DG drops below this minimum level, an islanding condition must have occurred. To detect this condition using the Beckwith Electric M-3410A or M-3520 relays, a *reverse underpower* element is applied. The "normal" condition, where the DG is importing power (the utility is exporting power to the DG facility), the pick-up value of the reverse underpower element is set less than the expected minimal power import by the DG facility. When the imported power level decreases (becomes less negative) , the reverse power perceived by the relay decreases, and when it *decreases* below the reverse underpower pick-up point for a specified time, the element asserts a trip command. This differs from the classic overpower concept of a reverse power element (32R), in which if the power flowing in a reverse direction *exceeds* (becomes more negative) a pick-up point for a specified time, the element asserts a trip command.

To enhance the security of this application, the generators output bias should be set so some import from the utility is always present (Gen Output = Facility Load – Bias). The bias amount is typically set for the largest single switched load in the DG facility. In facilities with small switched loads, such as hospitals, data centers and hotels, the bias is typically small. For large industrial facilities that contain large switched motors, a larger bias is typically required.

3.0 POWER ELEMENT CONVENTIONS WITHIN THE PROTECTIVE RELAYS

The Beckwith Electric M-3410A and M-3520 relays' directional power elements are configured by assigning a power sign, positive (+) for forward power or negative (-) for reverse power, and then selecting overpower or underpower application.

This configuration freedom allows the creation of four directional power element possibilities:

- Reverse Overpower (32R)
- Reverse Underpower (32R-U)
- Forward Overpower (32F)
- Forward Underpower (32F-U)

These are illustrated in Figure 3. The directional power elements are individually configurable with a two-step process.

1) Selection of the pick-up level, positive (forward) or negative (reverse):
   a) *Positive Value*– this places the pick-up point in the forward power area of the element, creating a forward-power element
   b) *Negative Value* – this places the pick-up point in the reverse power area of the element, creating a reverse-power element

2) Selection of overpower or underpower application:
   a) *Overpower*
      i) In the reverse overpower mode (Figure 3a), an increase in reverse power flow that exceeds the pick-up value for a specified time will assert a trip command.
      ii) In the forward overpower mode (Figure 3c), an increase in forward power flow that exceeds the pick-up value for a specified time will assert a trip command.

b) *Underpower*

i) In the reverse underpower mode (Figure 3b), a decrease in reverse power flow that is below the pick-up value for a specified time will assert a trip command.

ii) In the forward underpower mode (Figure 3d), a decrease in forward power flow that is below the pick-up value for a specified time will assert a trip command.

a) Power Plot of Reverse Overpower Element, 32R

b) Power Plot of Reverse Underpower Element, 32R-U

Figure 3 Power Plots of Directional Power Elements

c) Power Plot of Forward Overpower Element, 32F

d) Power Plot of Forward Underpower Element, 32F-U

Figure 3 Power Plots of Directional Power Elements, continued

4.0 RELAY SENSITIVITY

Relay sensitivity must be considered when applying the 32 function to the low trip values frequently encountered in these applications. Before setpoint calculations are considered, the current available to the relay at the desired trip value should be calculated and compared to the minimum current sensitivity of the relay being used. For the M-3520, a minimum of 5 ma must be available in the relay at the desired trip value for the relay to operate. For the M-3410A, this value is a minimum of 100 ma. If the desired trip point is below the minimum current sensitivity levels given, the current transformer ratio must be reduced or the trip values increased. It is probably obvious that the performance of the current transformers is more significant than the relay as far as accuracy is concerned.

5.0 APPLICATION OF A REVERSE UNDERPOWER ELEMENT FOR DG LOW IMPORT POWER PROTECTION

The reverse underpower element may be applied for low import power protection. Combining the conventions of the Beckwith Electric M-3410A and M-03520 relays with the power element graphics, we illustrate how this is achieved in Figure 4. This is the application specified by California Rule 21.

Figure 4 One Line Diagram with Power Plot of Reverse Underpower Element, Low DG Import Power Application

Examples of the values for the rated power of the DG generator, CT ratio and VT ratio are depicted.

As long as power is being imported by the IPP, a trip will not occur. As soon as the imported power drops below (less negative) the reverse underpower pick-up, a trip command will be issued.

The 32R-U element is supervised by the utility interconnection breaker position. The 32R-U element is blocked if the interconnection breaker is open. This prevents misoperations when the generators are not paralleled to the utility. Continuity by the breaker contact indicates that the breaker is open, and therefore the generator is not paralleled with the utility.

6.0 CALCULATIONS AND RELAY PROGRAMMING

The 32R-U element is set in per unit (p.u.), with 1 p.u. being based on the generator's nominal power rating. As shown in Figure 5, you set the nominal current to the generator-rated secondary current, and the nominal voltage to the generator-rated secondary voltage. The relay now knows the generator's full-load rating which is 1 p.u.

Nominal current:

I_{nom} = kVA_{gen} / kV_{gen} * √3 * CT Ratio
= 750 / (0.480 * √3 * 2000/5)
= 2.25 A

Nominal voltage:

V_{nom} = $V_{pri\ (rated\ voltage)}$ / VT Ratio
= 480 / 480/120
= 120 V

CT Ratio: 2000/5 = 400
VT Ratio: 480/120 = 4

Sensitivity check - M-3410A (minimum sensitivity 100mA)

Trip point = 750 kVA * .05 = 37.5 kVA
I pick up = 37.5 kVA/ √3 * 480 * 400 = 112 ma (current sensitivity okay)

Figure 5 Relay Set-Up Screen

Figure 6 Power Element Setting Screen

By selecting the setting of (-)0.05 p.u. power as shown in Figure 6, the relay will trip if the import of power from the utility falls below 0.05 p.u. of the generators' capacity. In this example, a trip will be issued if the import power becomes less negative than 0.05 p.u. ∗ 750 kVA, or 37.5 kVA.

7.0 EXCEPTIONS AND CALCULATIONS FOR EXCEPTIONS

The above calculations are specifically designed for the State of California Rule 21 requirement that the import underpower set point be based on 5% of the facility gross nameplate rating of its generator(s). Often, the application does not lend itself to this simplistic approach. For example, consider an 80 kW generator being installed on a 480 volt system where the current transformer ratio is 1200/5. The calculated I_{nom} for this application is 0.4 amperes which is outside the range of the M-3410, M-3410A and M-3520 relays. Other state and utility Interconnect Documents allow for a variety of set point requirements. These cover a fairly wide range of set points and do not allow for a standardized approach to the calculations.

The calculation of the set point for the 32 function requires a basic understanding of how the relay calculates the power quantity. The relay set point is based on a PU (Per Unit) value that is derived from the I_{nom} and V_{nom} entered in the relay set up screen. These quantities also establish the metering range displayed by the relay. The set point is the desired trip value in secondary terms divided by the PU value established by the I_{nom} and V_{nom}. The calculation of the PU power for a VT configuration of L-G is determined by the equation $P = (3)(I_{nom})(V_{nom})$. For VT configurations of L-L or L-G to L-L, the equation is $P = \sqrt{3}\,(I_{nom})(V_{nom})$.

Sample calculation

Using the example described above in Section 7:

80 kW generator at 480 volts
CTR 1200/5 (240/1), VTR 480/120, VT configuration L-L
Desired trip point of 5% of generator nameplate
Relay type M-3410A, minimum sensitivity is 100mA
Relay type M-3520, minimum sensitivity is 5mA
Desired trip point (80kW)(.05) = 4kW

Check relay minimum current sensitivity 4kW/√3(480)(240) = 20 ma
M-3410A does not meet sensitivity requirement
M-3520 meets sensitivity requirement

Check relay minimum nominal current setting
Calculate I_{nom} 80kW/√3 (480)(240) = 0.4 amps Below minimum relay setting range of 0.5A

Calculate equivalent pickup setpoint based on 0.5A minimum setting
Minimum I_{nom} = 0.5 amps
Calculate V_{nom} 480/4 = 120 volts
Relay PU = √3 (0.5)(120) = 103.9 watts
Trip point secondary = 4kW/(ctr)(vtr) = 4kW/(240)(4) = 4.167 watts
Relay set point = trip value/per unit value = 4.167/103.9= **0.04 PU**

Alternate method:
The trip point secondary can also be established as √3 (20ma)(120) = 4.167 watts
Therefore, comparing equations, we find that trip value/per unit value is equal to current at trip/ I_{nom}.
Relay set point = 20ma/.5 = **0.04 PU**

8.0 CONCLUSIONS

When a DG is under contract never to export power to the utility, or, the minimum load of the DG facility is greater than the maximum aggregate load of all generators within the facility, import underpower protection (from the DG's perspective) may be applied as a supplemental form of loss of parallel operation protection. Understanding how this protection is implemented from the relay perspective is paramount for proper application. As the number of DGs and load on a given feeder is dynamic, a situation may develop where a feeder is separated from the utility, and the aggregate power from all connected DGs equals the feeder's connected load. The use of import underpower protection will succeed in detecting the islanding condition where the undervoltage (27), overvoltage (59) and over/underfrequency (81O/U) elements may not be able to.

There are many cases that may require the assumption of a nominal current. This is the most available variable in the relay that can be used to adjust the PU, value required in the establishment of relay set points. The nominal voltage is used for all of the voltage functions in the relay and therefore should not be assumed. It should be noted that the lower the nominal current, the higher the set point relative to a common trip value. It should also be noted that an assumed nominal current will impact the metering values displayed on the secondary monitoring screen of the relay.

The metering values in PU will be incorrect by the ratio of the assumed nominal current to the proper nominal current. This might occur where the interconnection metering is based on a step up transformer size that gives 4 amps as the correct nominal current and the assumed nominal current has to be 2 amps to get the needed set point. The PU metering in the *secondary* monitoring screen of the relay will read twice as high as would be expected if 4 amps were used as the nominal current. The power factor should be correct and the watts and vars proportionately correct. If the relay is configured correctly, i.e., the nominal voltage, VT configuration, and VT / CT ratios are all entered correctly; the *primary* monitoring screen will read the KW and KVAR correctly.

Also, in the case of the M-3410A relay, the 46 function is based on the nominal current entered into the set up screen. Care must be taken in setting this function since it will have to be corrected for the difference between the assumed nominal current and the correct one.

9.0 REFERENCES

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