

Auto-Check Circuit Breaker Interrupting Capabilities

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Paper published in *IEEE Computer Applications in Power*, Vol. 14, No. 1, January 2002, pp. 24-28.

Circuit breakers in a utility network are designed to quickly isolate short-circuited equipment from the rest of the system. The short-circuit current changes with switching operations and with the addition and removal of generating sources. Hence, electric utilities must check their breakers periodically using computer simulation to ensure that the breakers are capable of interrupting the short-circuit currents. The recent proliferation of independent power producers (IPP) has made breaker-rating studies a much more routine procedure for utility engineers. The aim of these studies is to see if the existing circuit breakers are adequate when the proposed generators are put in service. The need for efficient and accurate breaker-rating software is greater now than ever.

The benefit of computerized breaker-rating studies has been recognized for many years. Most utilities have breaker-rating software of some kind. What is not well known about breaker rating is the inherent difficulty in rating breakers using the sequence-network model that is commonly used for short-circuit studies. The breaker-rating program was improved by making the description of the breaker more flexible, universal, and easy to apply. This is the breaker connection model.

Sequence-Network Model Difficulties

The difficulty arises from the absence of breakers in these sequence-network models. Figure 1 illustrates this point. On the left side of Figure 1 is the actual circuit configuration in which four circuit breakers connect together at a

bus. On the right side of Figure 1 is the corresponding sequence-network model. Note that there are no breakers in this circuit at all. The challenge in this example is to find a way to rate the four breakers correctly using the network model on the right-hand side. It should be noted that the ring scheme is only one of many common breaker configurations found in utility networks. Many of these are more complex in topology.

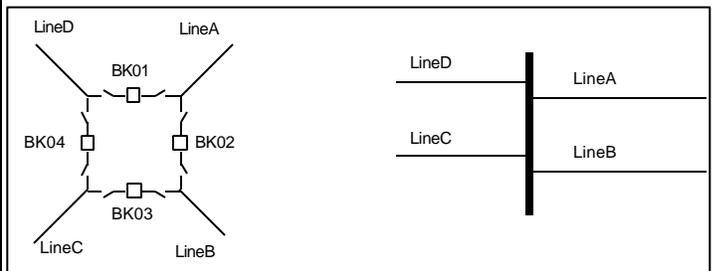


Figure 1. Contrast the (a) ring scheme connecting four lines to a bus with the (b) equivalent circuit model in which the breakers are not represented

Over the years, utility engineers have found ways to rate breakers using the sequence-network model. These methods were utilized 2 years ago when the first version of our breaker-rating program was written. Experience shows that while these methods are adequate in the simple configurations, they are lacking in a significant number of cases. The deficiency of the breaker-rating program is costly to a utility, because it means utility engineers have to sift through the questionable cases by hand to find the breakers that are truly underrated.

Breaker Connection Model

For each circuit breaker, the user is asked to specify up to two separate lists of network devices that are protected by the breaker. Usually (but not always) one list is for devices on one side of the breaker, and the other list is for devices on the other side. The protected devices must be elements of the sequence-network model, such as buses, generating units, transmission lines, capacitors, and transformers.

The breaker-rating program deduces from the list of network devices in the connection model what faults need to be simulated. Different combination of faults are used to check breakers that protect generating units and for branches, for example. The program automatically considers branch contingencies when the two groups contain more than one branch.

The connection model also tells the breaker-rating program how to determine the amount of short-circuit current that will pass through the circuit breaker. Specifically, it asks the user to specify for each group whether the breaker will sense the “maximum device current” or the “total group current.” To check a breaker that senses the maximum device current, the program compares the breaker rating against the highest device current in the group. To check a breaker that senses the total group current, the program compares the rating against the vector sum of all the device currents in the group.

Examples of Application in Typical Configurations

The following examples illustrate how this connection model is put into practice for some typical breaker configurations.

Line Breaker

The line breaker is a simple, but important, example. An illustration of a line breaker is shown in Figure 2. The connection model is as follows:

Group 1: Members: Line A; Method: Group current.
Group 2: Empty.

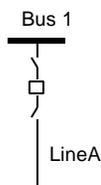


Figure 2. Line breaker

The program automatically simulates three faults whenever the breaker protects a branch. The first is a fault at bus 1. The breaker current in this case is the “group current,” or simply the short-circuit current that flows through the line at the bus 1 end. (Note: When a group contains just one piece of equipment, the group current is the same as the maximum device current.) The second fault is a close-in fault in front of the breaker. The program does not actually perform this simulation because it can deduce the needed breaker current using the previous fault solution. The third fault is a close-in fault with the remote end open. In practice, this is computed as the total bus-fault current with the line outaged. The line breaker’s rating is compared to the maximum of these three breaker currents. We will refer to this as the “maximum line current” from now on.

Ring Bus

This is the ring-bus configuration of Figure 1. For the breaker BK01, we use the following connection model:

Group 1: Members: LineA; Method: Group current.
Group 2: Members: LineD; Method: Group current.

The program automatically simulates outage contingency cases whenever the connection model has more than one branch. Specifically, the program computes these four currents:

- Maximum line current for LineA
- Maximum line current for LineA with LineD outaged
- Maximum line current for LineD
- Maximum line current for LineD with LineA outaged.

The program compares the breaker rating to the highest of these four currents.

The connection model for the other breakers in the ring-bus scheme is the same, except for the obvious difference in the set of protected lines.

Breaker and a Half

The breaker-and-a-half configuration is shown in Figure 3. There are two different connection models for the breakers in this scheme. One is for breakers in the middle (BK02 and BK05), with a line on each side. The other is for the rest of the breakers, which are connected to a line on one side, and the bus on the other.

For the middle breaker BK02, the connection model is:

Group 1: Members: LineA; Method: Group current.
Group 2: Members: LineB; Method: Group current.

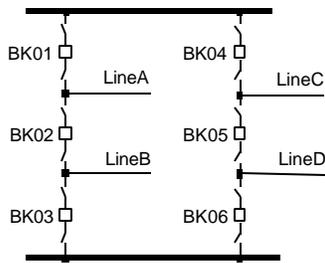


Figure 3. Breaker-and-a-half configuration

The procedure for the middle breaker is exactly the same as in the ring-bus example. For the breaker BK01, in addition to protecting the adjacent line, we must consider the possibility that it may have to interrupt the total fault current. The connection model is therefore:

Group 1: Member: LineA; Method: Group current.
Group 2: Member: Bus; Method: Group current.

In this case, the program compares the breaker rating to the higher of these fault currents:

- Maximum line current for LineA
- Total fault current at the bus.

Transfer Breaker

The transfer-breaker configuration is shown in Figure 4. Breaker BK01 is normally open. When one of the other breakers is taken out of service, BK01 is used (in conjunction with some of the switches shown) to bypass the out-of-service breaker. Clearly, the transfer breaker BK01 must be rated as high as the breakers that it bypasses. The connection model is therefore:

Group 1: Members: LineA, LineB, LineC; Method: Max device current.
Group 2: Empty.

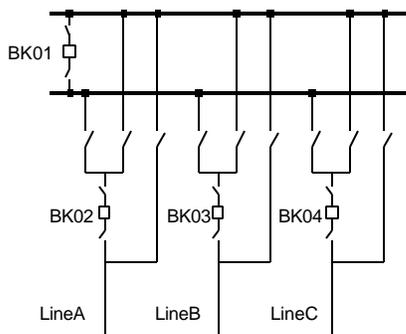


Figure 4. Configuration with a transfer breaker BK01

The program computes these currents compute for this connection model:

- Maximum line current for LineA
- Maximum line current for LineA with LineB outaged
- Maximum line current for LineA with LineC outaged

- Maximum line current for LineB
- Maximum line current for LineB with LineA outaged
- Maximum line current for LineB with LineC outaged
- Maximum line current for LineC
- Maximum line current for LineC with LineA outaged
- Maximum line current for LineC with LineB outaged.

The program compares the rating of the transfer breaker to the highest of these currents. The other breakers in this scheme are rated the same way as the line-breaker example.

Bus Tie

A bus-tie configuration is shown in Figure 5. Bus-tie breaker BK01 connects two bus bars, each with two lines connected. This breaker, therefore, must be rated using the sum of the line currents on each bus bar. We formulate the connection model as follows:

Group 1: Members: LineA, LineB; Method: Group current.

Group 2: Members: LineC, LineD; Method: Group current.

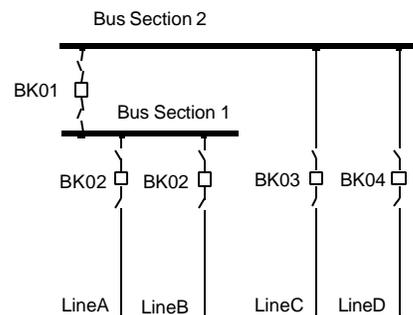


Figure 5. Configuration with a bus tie

The currents computed for this connection model are the following:

- Sum of line current for LineA and LineB for a fault on bus section 2
- Same fault, but with LineC and LineD outaged
- Sum of line current for LineC and LineD for a fault on bus section 1
- Same fault, but with LineA and LineB outaged.

Generator Breaker

A generator-breaker configuration is shown in Figure 6. The generator model in our short-circuit program allows multiple units in each generator. When a generating unit is specified as

a protected device in the connection model, the breaker-rating program automatically considers the case when the breaker has to interrupt a fault on the system side and the cases when the breaker has to interrupt a fault on the generating-unit side. The connection model for a generator breaker is:

Group 1: Member: GenUnitA; Method: Group current.
Group 2: Empty.

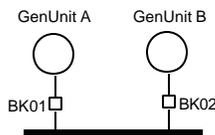


Figure 6. Breaker that protects a generating unit

In practice, the program simulates a single fault at the generator bus and compares the breaker rating to the higher of these two currents: the total fault current and the fault current from the generating unit.

Distribution Breaker

The distribution breaker configuration is shown in Figure 7. This is an interesting case in which the breaker protects a distribution feeder that is not represented in the sequence network. We can check this breaker by the following connection model:

Group 1: Member: Bus1; Method: Group current.
Group 2: Empty.

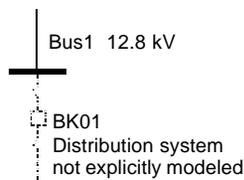


Figure 7. Distribution breaker

Standards

The utility industry has established standards for checking breaker ratings. Listed in the Further Reading section of this article are references for the IEEE/ANSI and IEC standards. Here is a synopsis of the steps in rating circuit breakers according to the ANSI/IEEE standard.

The IEEE/ANSI standard mandates the use of asymmetrical short-circuit current at the moment of breaker contact parting for checking the adequacy of circuit breakers. This current is treated as the sum of two components: the

symmetrical (or steady-state ac) component and the asymmetrical (or the decaying dc) component that takes place because of system reactance. The symmetrical ac component can be obtained readily from sequence-network-based short-circuit calculations. The asymmetrical component of the breaker current is accounted for by the fault-current-multiplier method. The core of this method is a set of curves depicting the ratio between the total current to the symmetrical current, as a function of system X/R ratio. The reactance value (X) forming the X/R ratio used in the curves is obtained from an X-only equivalent network in which all resistance is set to zero. The resistance value in the ratio is obtained from R-only equivalent network. Specifically, these are the steps that must be followed in checking the rating of each breaker:

- Simulate a fault in the complete network to obtain symmetrical component of breaker current
- Simulate a fault in the X-only network and again the same fault in the R-only network to obtain X/R ratio
- Select a fault-current-multiplier curve using the breaker parting time, and look up the value of the curve at the computed X/R ratio
- Adjust the symmetrical current using the multiplier to get the total breaker current
- Determine the breaker's interrupting capability, which is a function of the operating voltage and the type of fault, e.g., three-phase or single-line-to-ground (This procedure varies depending on whether we are working with a total-current rated breaker or a symmetrical-current rated breaker.)
- Derate the breaker rating, as appropriate, for the effects of reclosing
- Compare the breaker rating to the total breaker current and report any deficiencies
- Determine the momentary current of total-current rated breakers and the close-and-latch rating of symmetrical-current rated breakers, compare this value to the associated rating, and report any deficiencies.

Speed and Storage Considerations

Rating breakers is computationally intensive. This point is illustrated with the statistics of an actual case with 3,194 circuit breakers in a network with 3,060 buses; a total of 13,962 short-circuit simulations were required to rate the breakers. Two-thirds of these simulations were

needed to compute the ANSI X/R ratio. The rest were used to compute the breaker current. Many breaker-rating programs are written as add-on scripts to a short-circuit program. Such programs are usually lacking in their user interface, and they are slow to execute and have limited flexibility in breaker modeling. Ideally, a breaker-rating program should be a specialized compiled program that can retrieve the breaker data from either a database or a flat file.

Our breaker-rating program, which was written with C++, was able to rate the 3,194-breaker case and create a written report in 55 seconds. The case was run on a personal computer with an Intel Pentium processor running at 300 MHz. Another consideration we faced in our implementation is where to put the circuit-breaker data on a graphical display of the sequence network model. The best solution we found was to associate the breakers with the bus object. This makes it possible for multiple breakers to reside at each bus, and for having each breaker protect one or more elements that are connected to that bus. To edit the breaker data in a dialog box, the user has to first open the bus object and then click on the breaker's name on the Breaker tab. An example of a breaker dialog box is shown in Figure 8.

At Dominion Virginia Power, the breaker-rating program has been a big time saver. Dominion Virginia Power is an investor-owned utility serving approximately 1,923,000 customers in Virginia and 105,291 customers in North Carolina. The service territory covers 30,000 square miles, which includes 65% of the land area of Virginia and part of northeastern North Carolina. The transmission and distribution facilities include 60,800 miles of transmission and distribution lines and approximately 3,233 breakers. One of the biggest challenges we have faced over the last couple of years is checking the short-circuit duty on these 3,233 breakers. Any time the system has had major changes (such as new generation), it is important to check the duty on these breakers. In the past, this has been a very time consuming process, sometimes taking days to complete. The breaker ratings module has now given us the ability to include in our short-circuit model a way to include the breakers and a quick check of their duty rating. Once the breakers are modeled in the system, all that is required is to make the changes to the system model and then run a quick check. This type of program has reduced to minutes what used to take days. An even more important reason to improve the productivity of

breaker duty checking on a system of this size is the large number of new generation requests now being realized. Over the last year, Dominion Virginia Power has had over 100 requests for new generation on their system. Without a productivity tool to check breaker duty, this would be an almost impossible task to keep up with. Many utilities today are facing the same problem and are searching for tools to solve this problem.

We found the connection model to be superior to the classical methods, but there are still a small percent of cases that cannot be characterized by this connection model. These cases usually involve circuits in which the breaker current goes up significantly when certain branches (not directly connected to the breaker) are taken out of service. This deficiency can be remedied by simply allowing the user to specify additional outage cases for each group of the connection model.

Figure 8. Dialog box for a breaker rated on the total-current basis

The greatest hurdle in utilizing a breaker-rating program in a utility is perhaps the manpower required to enter the breaker data. But once the breaker data is entered into a database, a

breaker-rating program will greatly reduce the work required to ensure that the breakers will work properly in the event of a fault.

For Further Reading

Guide for Calculation of Fault Currents for Application of AC High-Voltage Circuit Breakers Rated on a Total-Current Basis, ANSI/IEEE Standard C37.5, 1979.

AC Circuit Breakers Rated on a Symmetrical Current Basis – Preferred Ratings and Related Required Capabilities, ANSI/IEEE Standard C37.6, 1979.

Short-Circuit Current Calculation in Power Systems, International Standard IEC 909, 1988.

Procedure to Meet the Requirements of IEC 909 for the Calculation of Short Circuit Currents in Three-Phase AC Power Systems, the Electricity Association Engineering Recommendation G.74.

Biographies

Thanh C. Nguyen received his B.S. and M.S. degrees in nuclear power engineering from Moscow Power Engineering Institute in Russia and an M.S. degree in energy planning and policy from the Asian Institute of Technology based in Bangkok, Thailand. He completed his Ph.D. work in power system reliability analysis at the University of Wisconsin at Milwaukee. He is a member of IEEE.

Sherman Chan received his B.S. degree from Harvey Mudd College and his Ph.D. degree from M.I.T., both in engineering. He worked at Bonneville Power Administration and at System Control, Inc. before founding ASPEN in 1986. He is a Senior Member of IEEE and a fellow of the Hertz Foundation.

Ronnie Bailey received a B.S. in Electrical Engineering in 1980 from West Virginia Institute of Technology. He is presently employed with Dominion Virginia Power and is Manager of Bulk Power Engineering in the System Protection department. Ronnie has over 20 years of experience in the utility field most of which is within System Protection. He is an IEEE member and participates in the Power System Relaying committee. He is a member of the Georgia Tech Relaying conference committee. He holds Professional Engineer licenses in New Jersey, Vermont, and Virginia.

Thanh Nguyen received his B.S. in electrical engineering from Virginia Tech and is a registered engineer in Virginia. He started work with Dominion Virginia Power in the area of protective relaying and has held various positions in the protection area for the last 20 years. He is presently an Engineer III in the System Protection and Process Control department. His responsibilities include engineering support, computer application, and development.