Paralleling Switchgear: Documenting the Sequence of Operation with Charts

The sequence of operation for a paralleling switchgear project can be complex. Because no two power systems are exactly the same, each should be custom-designed to meet the requirements and challenges associated with the project application. To reduce guesswork and ambiguity during system design and operation, Kohler Power Systems has developed sequence charts that document how a system will respond to both normal operations and system failures. This intuitive approach helps ensure that the system will operate as designed with no surprises.

A concise, detailed sequence of operation is perhaps the single most important step when designing paralleling switchgear (or any system capable of automatic operation). A traditional narrative-based sequence of operation (below, left) may not clearly illustrate the timing of events or combine normal operation with how the system responds to failure. Kohler’s unique chart-based sequence of operation (below, right) offers a number of benefits, including step-by-step explanation of sequence, timing and response to failure. These multipurpose charts can also be used for submittal reviews, test procedures and operation and maintenance manuals. They provide a single point of reference when seeking to understand the operation of the paralleling switchgear.

This article describes the sequence chart approach, how a chart is custom-created for an individual system, and its benefits in the design, testing and training processes.

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**Section 1 Modes of Operation**

1.1 Emergency Mode

1.1.1 Loss of utility

The loss of a utility phase may be due to a fault in the PCC. If this event expires, than the following sequence occurs:

1. The closed utility breaker opens.
2. The generation starts.
3. The load generation is initiated, which synchronizes with the bus. From this point forward, both generators keep either on-line or off-line in a paralleling switchgear.
4. The other generator synchronizes to the bus, when synchronized, its circuit breaker opens.
5. With both generators on-line, the tie breaker closes.

*NOTE: Using the HMI, the operator can preset the system to automatically signal a utility switch to open.*

6. The tie breaker and the generator breakers open.

7. If a load managed control is in A or B mode, the following loads are shed:
   - Required GOL Bypass timer starts.
   - All available generator start.
   - Utility breaker UB opens.
   - Utility breaker UA is open. Bus A Open Transfer timer starts.
   - Utility A Failure timer starts.
   - The first generator reaches rated voltage and frequency.
   - The utility breaker closes.
   - Generator main breaker GMB closes.
   - Generator main breaker GMA opens.
   - The other generator is still timing.
   - Bus B Open Transfer timer expired.
   - The first generator breaker closes.
   - The other generator breaker closes.

7. If a load managed control is in A or B mode, the following loads are shed:
   - Based on the Load-Management settings, the system will automatically start or stop the individual generator.
   - The system remains on generator power and utility power is available, the system initiates the return to utility sequence. If the system is on generator power, the utility breaker is available, the system initiates the return to utility sequence.

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DESIGNING A PARALLELING SWITCHGEAR PROJECT

There are four distinct stages of designing a paralleling switchgear system.

1. Creating the single-line drawing
   The single-line drawing illustrates how components of the electrical system are connected and the available routes through which power may travel in the system.

2. Establishing the sequence of operation
   The sequence of operation describes the steps the system will take to change from one state to another, such as moving from “on utility power” to “on generator power.” A well-written sequence will describe both normal operation and any alternate sequences the system takes if there is a failure during normal operation.

3. Selecting controls
   Controls enable a system to perform the specified sequences, allow for operator interaction and provide all required metering and protection. During the control selection phase, consideration should be given to both the level and redundancy of the automatic controls, as well as to any manual controls required for operator intervention in the event of an automatic control failure.

4. Determining the switchgear structure
   The structure of the paralleling switchgear lineup is the physical representation of the single line. It contains the circuit breakers, controls and meters.
   Each stage builds on the previous one; following them in order is key to a successful project.

While progressing through each design stage, it is important to review decisions made in the prior stages to be sure they remain valid and make any necessary adjustments if changes are made. For example, if the drawing is revised to add a bus tie breaker to the single line, it is important that the sequence is updated to indicate the purpose of the tie breaker and its role in the sequence of operation.

Each of the four stages used to design paralleling switchgear is vital to the creation of a cohesive system. However, the most challenging – and often the most important for proper operation – is establishing the sequence of operation. This is especially important for complex projects with multiple utilities, where a detailed and precise sequence of operation provides the foundation upon which the project is built. Critical to the sequence of operation is an understanding of how the system works normally and how it responds if there is a failure in the normal sequence, such as a breaker failing to open or close.

A NEW APPROACH – SEQUENCE CHARTS

The unique charts developed by Kohler Power Systems are a distinctive approach to documenting the sequence of operation. These intuitive charts offer benefits for everyone involved in the design and operation of the project.

- They eliminate the ambiguity of knowing how the system responds to both normal operations and system failure.
- They are easier to read than a typical flowchart.
- They clearly show system response, timing of response, and what the system and operator can do if the system fails to respond properly.
- They provide a checklist for testing and commissioning the paralleling switchgear.

Each sequence has two charts – the sequence itself and the response to abnormal conditions.

- The sequence lists the steps the system will take from the initial state to the final state as well as the expected system response to each step.
- The response to abnormal conditions describes the system response and the action an operator can take if the system does not respond as expected to an event.

The chart-based method describes the operation that a typical paralleling switchgear sequence takes in a series of steps that transition from an initial state, such as “on utility power,” to a final state, such as “on generator power.” The number of charts for an individual project will vary depending on the number of normal states and the different types of transitions, such as open or closed, between the states.
**The Five Steps in Creating a Sequence Chart**

Let's look at the five steps we take in creating the chart, and how they illustrate—in sequence—the system's loss of both utilities. The sequence to transfer from utility power is described in a series of steps. Within each step are an event and a corresponding system response to the event. Simultaneous responses to the same event are shown as separate response lines.

**The Five Steps in Creating a Sequence Chart**

1. **Determine the Initial State**
   - The initial state shows the status of each breaker in the power transfer sequence and the power status of each bus in the system.
   - In the initial state, the system is on utility power. Utility Breaker A (UA) and Utility Breaker B (UB) are closed and main breakers Generator Main A (GMA) and Generator Main B (GMB) are open. The chart shows the status of each breaker that is part of the power transfer sequence and the power status of each of the three buses in the system.

2. **Define the Triggering Event**
   - The triggering event starts the sequence. Examples might be the receipt of a remote start signal, the utility being out of tolerance or an operator pushing a button. For example, in Step 1, when UA and UB are out of tolerance, both the UA Failure timer and the UB Failure timer start.

3. **List Each Event (Step) and Corresponding Response**
   - Each step required to transition from initial state to desired final state is described. Each row in the sequence lists the required change in system state and the corresponding system response. For example, if a system is performing an open transfer back to the utility after a power outage, one of the events might be the opening of the generator main breaker and the startup of the open transfer timer (event/corresponding system response). See chart on page 5.

4. **List the Final State of the System**
   - The final state shows the status of each breaker in the power transfer sequence and the power status of each bus in the system.

5. **Determine ‘If Fail’ Scenarios**
   - Each system response is reviewed to determine if an “if fail” scenario is needed. In general, an “if fail” scenario is required for any response that involves a breaker opening or closing or a timer starting. This step preplans how the system should respond if a breaker fails to open or close or if something happens and a fail-safe timer expires. Responses that require an “if fail” scenario include a generator failing to start, a generator failing while running or generators becoming overloaded. In an “if fail” scenario, the “if fail” column in the sequence chart references the corresponding step in the “response to abnormal conditions” chart, describing the system's automatic response to that failure and the actions an operator should take to correct the system.

The power of the chart becomes evident in the next step of the sequence. When both utility failure timers expire or one timer expires while the other is still timing, the following things happen simultaneously:

- Utility breaker UA opens
- Utility breaker UB opens
- All available generators start
- Required GOL (Generator Online)
- Bypass timer starts

The chart not only shows how a system responds to an event but also when each response occurs. By showing each response on a separate line, the operator can refer to the corresponding step on the “response to abnormal conditions” chart (below) to determine how to correct an “if fail” scenario.

<table>
<thead>
<tr>
<th>INITIAL STATE</th>
<th>UA</th>
<th>Box A</th>
<th>GMA</th>
<th>Gen Bus</th>
<th>GMB</th>
<th>Box B</th>
<th>UB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>D</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>STEP</th>
<th>EVENT</th>
<th>RESPONSE</th>
<th>IF FAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Utility A and utility B out of tolerance.</td>
<td>Utility A Failure timer starts.</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>Both utility failure timers expire or one failing timers expire.</td>
<td>Utility breaker UB opens.</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>Utility breaker UB opens.</td>
<td>Utility breaker UB opens.</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>Utility breaker UB opens.</td>
<td>Utility breaker UB opens.</td>
<td>D</td>
</tr>
<tr>
<td>5</td>
<td>Utility breaker UB opens.</td>
<td>Utility breaker UB opens.</td>
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</tr>
<tr>
<td>6</td>
<td>All available generators start.</td>
<td>Required GOL (Generator Online).</td>
<td>F</td>
</tr>
<tr>
<td>7</td>
<td>Startup Shed Option: Based on the Load Management settings, loads on bus A are shed.</td>
<td>Generator main breaker GMB closes.</td>
<td>G</td>
</tr>
<tr>
<td>8</td>
<td>Generator main breaker GMB closes.</td>
<td>Generator main breaker GMA closes.</td>
<td>H</td>
</tr>
<tr>
<td>9</td>
<td>Generator Stability timer expires.</td>
<td>Generator main breaker GMA closes.</td>
<td>I</td>
</tr>
<tr>
<td>10</td>
<td>Generator main breaker GMA closes.</td>
<td>Generator main breaker GMA closes.</td>
<td>J</td>
</tr>
<tr>
<td>11</td>
<td>Bus A and B off generator power.</td>
<td>Startup Shed Option: Based on the Load Management settings, loads on bus B are shed.</td>
<td>K</td>
</tr>
<tr>
<td></td>
<td>Startup Shed Option: Based on the Load Management settings, loads on bus A and B are shed.</td>
<td>Generator Management Options become active if load and fault loads have been added.</td>
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**Sequence Chart (Example)**

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<td>3</td>
<td>Utility breaker UB opens.</td>
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Implementing a chart-based sequence of operation instead of a narrative-based sequence provides a way to comprehensively cover the “what ifs” while the project is still in the design stage. In addition, the sequence of operations chart serves as a checklist during testing to provide better quality assurance. In many cases, by simulating the sequence of operation and documenting it, the equipment performs at a higher level, onsite start-up time decreases and reliability increases.

THE PAYOFF OF KOHLER’S CHART-BASED APPROACH

Kohler’s chart-based approach to the sequence of operation provides a more effective way to look at sequencing. It ensures the stage is described without ambiguity and each step is clearly explained. More importantly, if a system failure occurs, the system’s response is already known – often eliminating guesswork and minimizing system interruption. Making complex systems simple – that’s the Kohler difference.

### Response to Abnormal Conditions Chart (Example)

<table>
<thead>
<tr>
<th>STEP FAIL</th>
<th>EVENT</th>
<th>SYSTEM RESPONSES</th>
<th>OPERATOR ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Utility A failure before Utility A Failure timer expires.</td>
<td>Bus A remain on utility A.</td>
<td>No operator action required.</td>
</tr>
<tr>
<td>B</td>
<td>Utility B power returns before Utility B Failure timer expires.</td>
<td>Bus B remain on utility B.</td>
<td>No operator action required.</td>
</tr>
</tbody>
</table>
| C         | Utility breaker UA fails to open. | Utility A remain failed, Utility B remain failed: Bus A is without power. Generator main breaker GMA does not close. | Option #1: Reset the Fail to Open alarm. System attempts to open utility breaker UA. When breaker opens, transfer automatically continues.  
Option #2: Manually open utility breaker UA. Transfer automatically continues if system is in Auto.  
Option #3: 1. Place system in Manual.  
2. Manually open utility breaker UA.  
3. If required, shed load.  
4. Manually close generator main breaker GMA. |
| D         | Utility breaker UB fails to open. | Utility B remain failed, Utility A remains failed: Bus B is without power. Generator main breaker GMA does not close. | Option #1: Reset the Fail to Open alarm. System attempts to open utility breaker UB. When breaker opens, transfer automatically continues.  
Option #2: Manually open utility breaker UB. Transfer automatically continues if system is in Auto.  
Option #3: 1. Place system in Manual.  
2. Manually open utility breaker UB.  
3. If required, shed load.  
4. Manually close generator main breaker GMA. |

Response to Abnormal Conditions Chart