Establishing the Sequence of Operation for Paralleling Switchgear

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INTRODUCTION

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, Rehlko 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 may not clearly illustrate the timing of events or combine normal operation with how the system responds to failure. Rehlko's unique chart-based sequence of operation 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.

DESIGNING A PARALLELING SWITCHGEAR PROJECT

There are four distinct stages of designing aparalleling switchgear system.

I. 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.

II. 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."

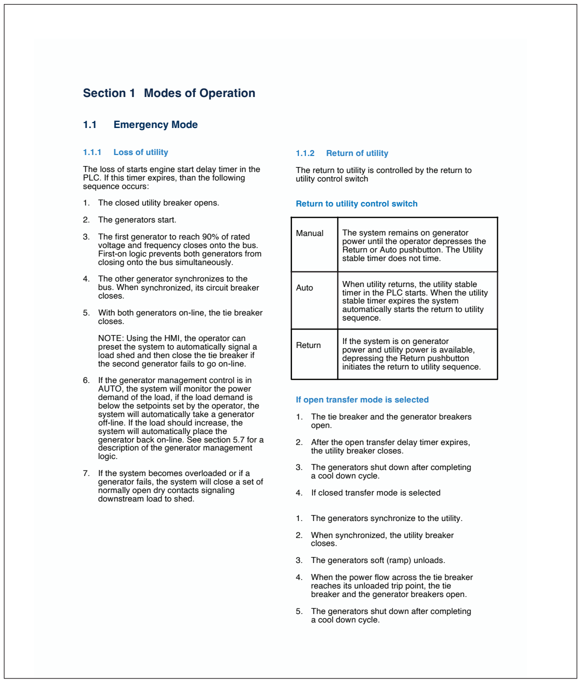
A well-written sequence will describe both normal operation and any alternate sequences the system takes if there is a failure during normal operation.

III. 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.

IV. 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.



Section 1 Modes of Operation

1.1 Emergency Mode

1.1.1 Loss of utility

The loss of starts engine start delay timer in the PLC. If this timer expires, than the following sequence occurs:

1. The closed utility breaker opens.
2. The generators start.
3. The first generator to reach 90% of rated voltage and frequency closes onto the bus. First-on logic prevents both generators from closing onto the bus simultaneously.
4. The other generator synchronizes to the bus. When synchronized, its circuit breaker closes.
5. With both generators on-line, the tie breaker closes.

   NOTE: Using the HMI, the operator can preset the system to automatically signal a load shed and then close the tie breaker if the second generator fails to go on-line.
6. If the generator management control is in AUTO, the system will monitor the power demand of the load, if the load demand is below the setpoints set by the operator, the system will automatically take a generator off-line. If the load should increase, the system will automatically place the generator back on-line. See section 5.7 for a description of the generator management logic.
7. If the system becomes overloaded or if a generator fails, the system will close a set of normally open dry contacts signaling downstream load to shed.

1.1.2 Return of utility

The return to utility is controlled by the return to utility control switch

Return to utility control switch

Manual	The system remains on generator power until the operator depresses the Return or Auto pushbutton. The Utility stable timer does not time.
Auto	When utility returns, the utility stable timer in the PLC starts. When the utility stable timer expires the system automatically starts the return to utility sequence.
Return	If the system is on generator power and utility power is available, depressing the Return pushbutton initiates the return to utility sequence.

If open transfer mode is selected

1. The tie breaker and the generator breakers open.
2. After the open transfer delay timer expires, the utility breaker closes.
3. The generators shut down after completing a cool down cycle.
4. If closed transfer mode is selected

1. The generators synchronize to the utility.
2. When synchronized, the utility breaker closes.
3. The generators soft (ramp) unloads.
4. When the power flow across the tie breaker reaches its unloaded trip point, the tie breaker and the generator breakers open.
5. The generators shut down after completing a cool down cycle.

Traditional Narrative-Based Chart

SEQUENCE CHART (EXAMPLE)

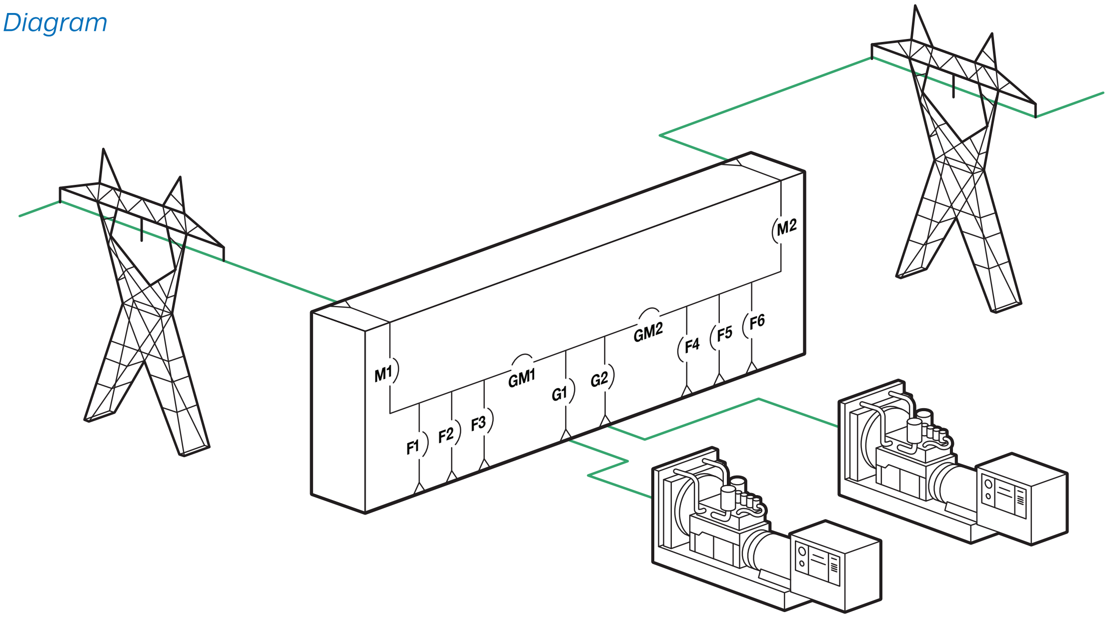
INITIAL STATE	UA	Bus A	GMA	Gen Bus	GMB	Bus B	UB
	X	E	O	D	O	E	X

STEP	EVENT	RESPONSE	IF FAIL
1	Utility A and utility B out of tolerance.	Utility A Failure timer starts.	A
		Utility B Failure timer starts.	B
2	Both utility failure timers expire or one timer expired while the other is still timing.	Utility breaker UA opens.	C
		Utility breaker UB opens.	D
		All available generators start.	
		Required GOL Bypass timer starts.	
3	Utility breaker UA is open.	Bus A Open Transfer timer starts.	
		Startup Shed Option: Based on the Load-Management settings, loads on bus A are shed.	
4	Utility breaker UB is open.	Bus B Open Transfer timer starts.	
		Startup Shed Option: Based on the Load-Management settings, loads on bus B are shed.	
5	The first generator reaches rated voltage and frequency.	The first generator breaker closes.	
6	The remaining generators independently reach rated voltage and frequency.	The remaining generators independently synchronize to the bus and close their respective circuit breakers.	E, F
7	Required generators are online and the bus A Open Transfer timer expired.	Generator main breaker GMA closes.	G
8	Generator main breaker GMA is closed.	Bus A is on generator power.	
		Required GOL Bypass timer stops.	
		Generator Stabilization timer starts.	
9	Generator Stabilization timer expires and bus B Open Transfer timer expired.	Generator main breaker GMB closes.	H
10	Generator main breaker GMB is closed.	Bus B is on generator power.	
11	Bus A and B on generator power.	Startup Shed Option: Based on the Load-Management settings, loads are added to the bus A and B.	I
		Generator Management Option: Becomes active if in Auto and all loads have been added.	

FINAL STATE	UA	Bus A	GMA	Gen Bus	GMB	Bus B	UB
	O	E	X	E	X	E	O

Rehlko Chart-Based Sequence of Operation

Single-Line Diagram



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.

NEW APPROACH–SEQUENCE CHARTS

The unique charts developed by RehlkoPower 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.

DETERMINE THE INTIAL SIZE

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.

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.

The "if fail" column directs the operator to the corresponding letter on the "response to abnormal conditions" chart, explaining how the system reacts if it does not respond as expected. In this example, the "if fail" describes the response that occurs if utility power returns before the failure timers expire.

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*.

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 to determine how to correct an "if fail" scenario.

LIST THE FINAL STATE OF THE SYSTEM

The final state of the system is described for each breaker within the power transfer sequence and the power status of each bus in the system.

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.

SEQUENCE CHART (EXAMPLE)

(1) INITIAL STATE	UA	Bus A	GMA	Gen Bus	GMB	Bus B	UB
	X	E	O	D	O	E	X

(2) STEP	EVENT	RESPONSE	IF FAIL
1	Utility A and utility B out of tolerance.	Utility A Failure timer starts.	A
		Utility B Failure timer starts.	B
(3) 2	(5) Both utility failure timers expire or one timer expired while the other is still timing.	Utility breaker UA opens.	C
		Utility breaker UB opens.	D
		All available generators start.	
		Required GOL Bypass timer starts.	
3	Utility breaker UA is open.	Bus A Open Transfer timer starts.	
		Startup Shed Option: Based on the Load-Management settings, loads on bus A are shed.	
4	Utility breaker UB is open.	Bus B Open Transfer timer starts.	
		Startup Shed Option: Based on the Load-Management settings, loads on bus B are shed.	
5	The first generator reaches rated voltage and frequency.	The first generator breaker closes.	
6	The remaining generators independently reach rated voltage and frequency.	The remaining generators independently synchronize to the bus and close their respective circuit breakers.	E, F
7	Required generators are online and the bus A Open Transfer timer expired.	Generator main breaker GMA closes.	G
8	Generator main breaker GMA is closed.	Bus A is on generator power.	
		Required GOL Bypass timer stops.	
		Generator Stabilization timer starts.	
9	Generator Stabilization timer expires and bus B Open Transfer timer expired.	Generator main breaker GMB closes.	H
10	Generator main breaker GMB is closed.	Bus B is on generator power.	
11	Bus A and B on generator power.	Startup Shed Option: Based on the Load-Management settings, loads are added to the bus A and B.	I
		Generator Management Option: Becomes active if in Auto and all loads have been added.	

(4) FINAL STATE	UA	Bus A	GMA	Gen Bus	GMB	Bus B	UB
	O	E	X	E	X	E	O

Response to Abnormal Conditions Chart

RESPONSE TO ABNORMAL CONDITIONS CHART (EXAMPLE)

STEP FAIL	EVENT	SYSTEM RESPONSE	OPERATOR ACTION
A	Utility A power returns before Utility A Failure timer expires.	Bus A remains on utility A.	No operator action required.
B	Utility B power returns before Utility B Failure timer expires.	Bus B remains on utility B.	No operator action required.
C	Utility breaker UA fails to open.	Utility A remains failed, Utility B remains failed: Bus A is without power. Generator main breaker GMA does not close. After the required generators are online, generator main breaker GMB closes.	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.
		Utility A remains failed, Utility B returns: Bus A is without power. The system transfers bus B from generator power to utility B power following the expiration of the Utility B Stable timer.	No operator action required.
		Utility A returns, Utility B remains failed: Bus A remains on utility A. Bus B remains on generator power.	Operator may manually transfer bus B from generator power to utility A power.
		Utility A and Utility B return: Bus A remains on utility A. The system transfers bus B from generator power to utility B power following the expiration of the Utility B Stable timer.	No operator action required.
D	Utility breaker UB fails to open.	Utility B remains failed, Utility A remains failed: Bus B is without power. Generator main breaker GMB does not close.	Option #1: Reset the Fail to Open alarm. System attempts to open utility breaker UB. When breaker opens, transfer automatically continues.

THE PAYOFF OF REHLKO'S CHART-BASED APPROACH

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.

Rehlko'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 important, 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 Rehlkodifference.

ABOUT THE AUTHOR

Mike Pincus is the Director of Sales Operations, Power Systems for Rehlko. Prior to his current role, he was the Manager of Switchgear Engineering where he was responsible for both development and application engineering for the paralleling switchgear product line. Pincus joined Rehlko in 1995 and holds a Bachelor of Science degree in electrical engineering from the University of Wisconsin-Madison and an M.B.A. from the University of Wisconsin-Milwaukee. He is a member of the Institute of the Electrical and Electronics Engineers (IEEE) and a registered professional engineer in the state of Wisconsin.

ABOUT POWER SYSTEMS

Power Systems, Rehlko's largest division, delivers worldwide energy solutions designed to ensure resilience for mission-critical applications of all sizes. Building on more than a century of expertise and dedication, the company offers complete power systems, including industrial backup generators (HVO, diesel, gaseous), enclosures, hydrogen fuel cells systems, automatic transfer switches, switchgear, monitoring controls, genuine parts and end-to-end services. As a global company with service partners in every country, Power Systems provides reliable, cutting-edge technology to keep industries and businesses running. www.powersystems.rehlko.com

ABOUT REHLKO

A global leader in energy resilience, Rehlko delivers innovative energy solutions critical to sustain and improve life across home energy, industrial energy systems, and powertrain technologies, by delivering control, resilience and innovation. Leveraging the strength of its portfolio of businesses – Power Systems, Home Energy, Uninterruptible Power, Clarke Energy, Heila Technologies, Curtis Instruments, and Engines, and more than a century of industry leadership, Rehlko builds resilience where and when the grid cannot, and goes beyond functional, individual recovery to create better lives and communities, and a more durable and reliable energy future.

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