VERTIV.

Technical Note

Performance Improvements with Sharing Inductors in Distributed Static Switch UPS Systems

Simplified Installation and Improved Performance

Contents

Introduction 3

Bypass sharing for redundancy and capacity 5

Bypass power sharing with cabling impedance differences 5

**Liebert® EXL S1 600kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 50 ft Bypass Path** 5

**Liebert® EXL S1 600kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 75 ft Bypass Path** 6

**Liebert® EXL S1 600kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 100 ft Bypass Path** 7

**Liebert® EXL S1 800kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 50 ft Bypass Path** 8

**Liebert® EXL S1 800kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 75 ft Bypass Path** 9

**Liebert EXL® S1 800kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 100 ft Bypass Path** 10

**Liebert EXL® S1 1200kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 50 ft Bypass Path** 11

**Liebert EXL S1 1200kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 75 ft Bypass Path** 12

**Liebert EXL S1 1200kVA UPS:
Comparison of Load Percent Distribution for Various Bypass Path Cable Length
Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 100 ft Bypass Path** 13

Field Results 14

Recommendations 14

Introduction

This paper explains how the impedances of UPS bypass paths should be controlled for paralleled distributed static switch systems and provides recommendations for controlling the cabling impedances to ensure efficient bypass power sharing.

In a paralleled distributed static switch system, when the critical bus is fed from the inverters, the load is actively shared between the modules through measurements, control circuits and firmware algorithms. When the critical bus is fed from the bypass static switches, there are no active controls to balance the load between the UPS modules. The total critical bus load will be distributed between the modules proportionally to the impedance difference through each bypass path. If the impedance is sufficiently different, one UPS bypass will assume a larger portion of the load, which could result in one module having greater than 100% load.

In large UPS systems, redundancy is defined as having at least one more UPS module than is required to feed the entire load should a single module be removed. Without redundancy, a system can carry the load of the data center only with all UPS modules in full operation. If two UPS modules are paralleled and the impedance in each bypass path is identical then each unit will have exactly 50 percent of the critical bus load while on bypass. Any mismatch in the impedance will cause one unit to have more than 50 percent of the load while the other UPS will have less than 50 percent.

For a distributed static switch UPS system, the impedances in the bypass paths must be matched sufficiently in order for each module to carry its rated load. If not, a full system load could cause one UPS to have, for example, 120 percent of the load and the other only 80 percent, which will cause one UPS to be overloaded and shutdown the entire load.

Bypass sharing for redundancy and capacity

One UPS unit can be removed in a redundant system while the critical load remains supplied from a conditioned, uninterruptible power source. Accurate bypass sharing is not critical, as the load on the bypass paths will never near 100 percent full load. However, if the redundant module is offline, then bypass sharing becomes important.

In a capacity system, the total critical load is such that all UPS's must be on-line to support the load; each UPS must be on and adequately sharing power under all circumstances. When operating on bypass, it is a function of impedance differences between each unit's bypass paths for the bypass circuits to share power.

The only means to balance the load when on bypass is to match the impedance in the bypass path for all the modules.

This can be achieved in two ways as follows.

1. Ensure that the parallel module bypass path impedances are the same. Check to ensure the cable lengths from the bypass source to the UPS input are the same, and the cabling from the UPS output to the critical bus are the same. In addition to matching cable lengths, one must take into consideration the impedance differences caused by different busbar lengths and breakers within the input and output switchgear along the bypass path.

2. Balance the load between the bypasses by inserting a known relatively large impedance into each bypass path. This "large" impedance has the effect of overcoming the smaller impedance mismatch. This approach allows for more cabling differences but only up to a certain point.

Figure 1 illustrates the simplified electrical circuit paths for the distributed bypass system. The circuit is composed of eight impedance elements:

1. **Input switchgear busbar**
2. **Bypass Input Breaker (BIB)**
3. **Input cabling**
4. **Back-Feed Breaker (BFB)**
5. **Bypass sharing inductors**
6. **Output cabling**
7. **Module Output Breaker (MOB)**
8. **Output switchgear busbar**

These are summed together to create the total impedance of the bypass path.

Figure 1 shows typical location of sharing inductors; however, the location can vary depending on site requirements and system design.

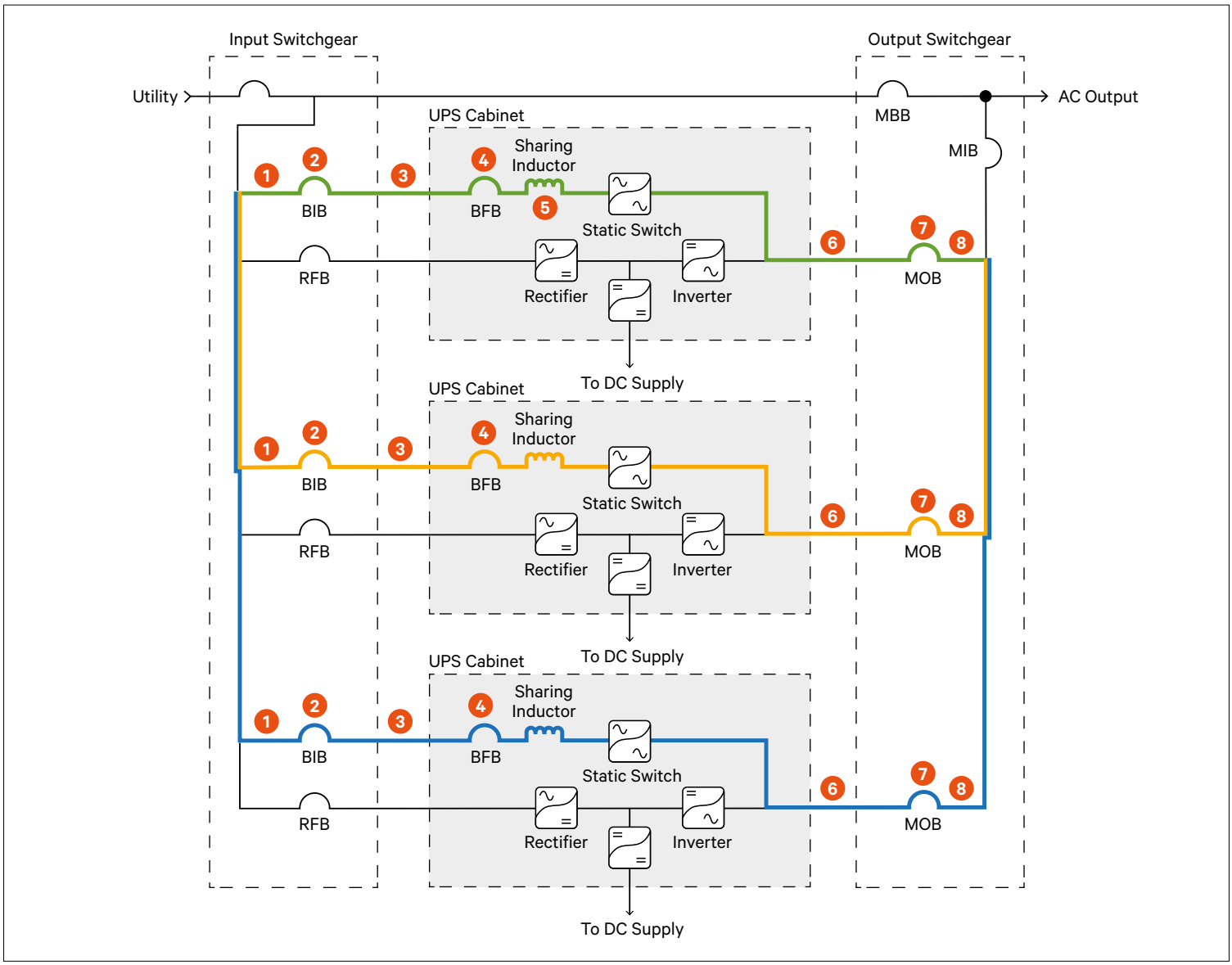

Figure 1: *Typical Distributed Bypass Electrical Circuit*

NOTE

In some UPS designs, inductive elements may be in the circuit whether the UPS is on bypass or inverter, in which case additional sharing inductors in the bypass line only may not be required.

Bypass power sharing with cabling impedance differences

Tables 1 through 18 illustrate several examples of bypass load sharing differences caused by bypass power cable length differences in a 3-module distributed bypass Liebert EXL S1 system, both without and with sharing inductors. **The impedance differences caused by elements in the input and output switchgear (busbar, BIB, MOB) are not considered in this analysis, but must be taken into consideration to calculate the total impedance for each bypass path.** For these examples, the cabling is determined based on the Vertiv-recommended conductor size and number of conductors per phase.

The data tables are grouped according to UPS power rating and bypass path cable length difference. The rows are grouped into sections to illustrate the load sharing effect of no cable length differences all the way up to a 20% cable length difference. The left table on each page shows the load sharing difference **without** sharing inductors. The right table on each page shows the load percent variation **with** sharing inductors. The shaded data indicates an individual UPS is in an overload situation sufficient to cause a non-continuous overload and subsequent load shutdown. Note that EXL S1 has a 110% continuous overload capability under typical operating conditions, so loads under 110% are not considered sufficient to cause a load shutdown.

The data in **Tables 1** through **18** show that it is important to have bypass sharing inductors to help control the cabling impedances due to likely variations in cable length if the bypass paths are to share the power without an overload situation. The effect of cabling differences amplifies for capacity systems as the number of paralleled UPS modules increases. The bypass impedance differences can further be amplified due to varying impedances present in switchgear busbar and breakers, leading to greater load sharing imbalance.

Liebert® EXL S1 600kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 50 ft Bypass Path

Table 1

Without Sharing Inductors, 100% System Load 50 ft Bypass Path, (3) 350kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	50
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	721	721	721
UPS Rated Load (%)	99.8	99.8	99.8
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	47,5
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	708	78	745
UPS Rated Load (%)	98.1	98.1	103.3
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	45
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	695	695	772
UPS Rated Load (%)	96.3	96.3	107
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	42,5
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	681	681	801
UPS Rated Load (%)	94.3	94.3	**110.9**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	40
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	665	665	831
UPS Rated Load (%)	92.2	92.2	**115.2**

Table 2

With Sharing Inductors, 100% System Load 50 ft Bypass Path, (3) 350kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	50
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	720	720	720
UPS Rated Load (%)	99.8	99.8	99.8
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	47,5
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	719	719	723
UPS Rated Load (%)	99.6	99.6	100.2
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	45
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	718	718	726
UPS Rated Load (%)	99.4	99.4	100.6
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	42,5
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	716	716	728
UPS Rated Load (%)	99.3	99.3	100.9
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	40
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	715	715	731
UPS Rated Load (%)	99.1	99.1	101.3

***Note:** Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 600kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 75 ft Bypass Path

Table 3

Without Sharing Inductors, 100% System Load 75 ft Bypass Path, (3) 350kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	720	720	720
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71,3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	708	708	744
UPS Rated Load (%)	98.1	98.1	103.1
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67,5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	694	694	771
UPS Rated Load (%)	96.2	96.2	106.9
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63.8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	680	680	800
UPS Rated Load (%)	94.2	94.2	**110.8**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	60
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	665	665	831
UPS Rated Load (%)	92.1	92.1	**115.1**

Table 4

With Sharing Inductors, 100% System Load 75 ft Bypass Path, (3) 350kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	720	720	720
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71,3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	718	718	724
UPS Rated Load (%)	99.5	99.5	100.3
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67,5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	716	716	728
UPS Rated Load (%)	99.2	99.2	100.8
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63,8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	714	714	731
UPS Rated Load (%)	98.9	98.9	101.3
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	60
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	712	712	735
UPS Rated Load (%)	98.7	98.7	101.9

Note: *Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 600kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 100 ft Bypass Path

Table 5

Without Sharing Inductors, 100% System Load 100 ft Bypass Path, (3) 350kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	100
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	719	719	719
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	95
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	707	707	744
UPS Rated Load (%)	97.9	97.9	103.1
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	90
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	694	694	771
UPS Rated Load (%)	96.1	96.1	106.8
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	85
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	679	679	799
UPS Rated Load (%)	94.1	94.1	**110.8**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	80
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	664	664	830
UPS Rated Load (%)	92	92	**115**

Table 6

With Sharing Inductors, 100% System Load 100 ft Bypass Path, (3) 350kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	100
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	719	719	719
UPS Rated Load (%)	99.6	99.6	99.6
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	95
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	717	717	724
UPS Rated Load (%)	99.3	99.3	100.3
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	90
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	714	714	729
UPS Rated Load (%)	99	99	101
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	85
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	712	712	734
UPS Rated Load (%)	98.6	98.6	101.7
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	80
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	709	709	739
UPS Rated Load (%)	98.3	98.3	102.5

Note: *Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 800kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 50 ft Bypass Path

Table 7

Without Sharing Inductors, 100% System Load 50 ft Bypass Path, (3) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	50
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	961	961	961
UPS Rated Load (%)	99.8	99.8	99.8
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	47,5
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	944	944	994
UPS Rated Load (%)	98.1	98.1	103.3
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	45
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	926	926	1029
UPS Rated Load (%)	96.3	96.3	107
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	42,5
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	907	907	1068
UPS Rated Load (%)	94.3	94.3	**110.9**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	40
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	887	887	1109
UPS Rated Load (%)	92.2	92.2	**115.2**

Table 8

With Sharing Inductors, 100% System Load 50 ft Bypass Path, (3) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	50
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	961	961	961
UPS Rated Load (%)	99.8	99.8	99.8
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	47,5
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	957	957	968
UPS Rated Load (%)	99.4	99.4	100.6
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	45
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	953	953	975
UPS Rated Load (%)	99.1	99.1	101.4
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	42,5
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	950	950	983
UPS Rated Load (%)	98.7	98.7	102.1
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	40
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	946	946	991
UPS Rated Load (%)	98.3	98.3	102.9

***Note:** Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 800kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 75 ft Bypass Path

Table 9

Without Sharing Inductors, 100% System Load 75 ft Bypass Path, (3) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	960	960	960
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71.3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	944	944	993
UPS Rated Load (%)	98.1	98.1	103.1
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67.5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	926	926	1029
UPS Rated Load (%)	96.2	96.2	106.9
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63.8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	907	907	1066
UPS Rated Load (%)	94.2	94.2	**110.8**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63,8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	907	907	1066
UPS Rated Load (%)	94.2	94.2	**110.8**

Table 10

With Sharing Inductors, 100% System Load 75 ft Bypass Path, (3) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	960	960	960
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71.3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	955	955	970
UPS Rated Load (%)	99.2	99.2	100.8
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67.5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	950	950	980
UPS Rated Load (%)	98.7	98.7	101.9
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63.8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	945	945	991
UPS Rated Load (%)	98.2	98.2	102.9
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	60
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	939	939	1001
UPS Rated Load (%)	97.6	97,6	104.1

Note: *Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 800kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 100 ft Bypass Path

Table 11

Without Sharing Inductors, 100% System Load 100 ft Bypass Path, (3) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	100
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	959	959	959
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	95
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	943	943	992
UPS Rated Load (%)	98	98	103.1
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	90
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	925	925	1028
UPS Rated Load (%)	96.1	96.1	106.8
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	85
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	906	906	1066
UPS Rated Load (%)	94.1	94.1	**110.8**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	80
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	886	886	1107
UPS Rated Load (%)	92	92	**115**

Table 12

With Sharing Inductors, 100% System Load 100 ft Bypass Path, (3) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	960	960	960
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71.3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	955	955	970
UPS Rated Load (%)	99.2	99.2	100.8
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67.5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	950	950	980
UPS Rated Load (%)	98.7	98.7	101.9
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63,8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	945	945	991
UPS Rated Load (%)	98.2	98.2	102.9
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	60
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	939	939	1001
UPS Rated Load (%)	97.6	97.6	104.1

***Note:** Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 1200kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 50 ft Bypass Path

Table 13

Without Sharing Inductors, 100% System Load
50 ft Bypass Path, (5) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	50
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	1441	1441	1441
UPS Rated Load (%)	99.9	99.9	99.9
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	47.5
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	1416	1416	1491
UPS Rated Load (%)	98.1	98.1	103.3
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	45
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	1390	1390	1544
UPS Rated Load (%)	96.3	96.3	107
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	42.5
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	1361	1361	1602
UPS Rated Load (%)	94.3	94.3	**111**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	40
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	1331	1331	1663
UPS Rated Load (%)	92.2	92.2	**115.2**

Table 14

With Sharing Inductors, 100% System Load
50 ft Bypass Path, (5) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	50
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	1441	1441	1441
UPS Rated Load (%)	99.9	99.9	99.9
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	47.5
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	1437	1437	1448
UPS Rated Load (%)	99.6	99.6	100.3
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	45
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	1434	1434	1456
UPS Rated Load (%)	99.3	99.3	100.8
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	42,5
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	1430	1430	1463
UPS Rated Load (%)	99.1	99.1	101.4
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	50	50	40
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	1427	1427	1470
UPS Rated Load (%)	98.8	98.8	101.9

Note: *Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 1200kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 75 ft Bypass Path

Table 15

Without Sharing Inductors, 100% System Load 75 ft Bypass Path, (5) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	1441	1441	1441
UPS Rated Load (%)	99.8	99.8	99.8
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71.3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	1416	1416	1490
UPS Rated Load (%)	98.1	98.1	103.2
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67.5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	1389	1389	1544
UPS Rated Load (%)	96.2	96.2	106.9
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63.8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	1361	1361	1600
UPS Rated Load (%)	94.3	94.3	**110.9**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
UPS	UPS #1	UPS #2	UPS #3
Bypass Path Cable Length (ft)	75	75	60
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	1330	1330	**1662**

Table 16

With Sharing Inductors, 100% System Load 75 ft Bypass Path, (5) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	1440	1440	1440
UPS Rated Load (%)	99.8	99.8	99.8
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71.3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	1435	1435	1450
UPS Rated Load (%)	99.4	99.4	100.5
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67,5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	1430	1430	1461
UPS Rated Load (%)	99.1	99.1	101.2
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63.8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	1425	1425	1471
UPS Rated Load (%)	98.7	98.7	101.9
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	60
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	1420	1420	1482
UPS Rated Load (%)	98.4	98.4	102.7

***Note:** Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Liebert® EXL S1 1200kVA UPS: Comparison of Load Percent Distribution for Various Bypass Path Cable Length Differences Between Systems With and Without Sharing Inductors, Nominal Voltage, 100 ft Bypass Path

Table 17

Without Sharing Inductors, 100% System Load 100 ft Bypass Path, (5) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	100
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	1440	1440	1440
UPS Rated Load (%)	99.7	99.7	99.7
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	95
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	1415	1415	1489
UPS Rated Load (%)	98	98	103.2
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	90
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	1388	1388	1543
UPS Rated Load (%)	96.2	96.2	106.9
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	85
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	1360	1360	1600
UPS Rated Load (%)	94.2	94.2	**110.8**
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	100	100	80
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	1329	1329	1661
UPS Rated Load (%)	92.1	92.1	**115.1**

Table 18

With Sharing Inductors, 100% System Load 100 ft Bypass Path, (5) 500kcmil per phase, Unity PF

No Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	75
Cable Length Difference (%)	0	0	0
UPS Bypass Current (Arms)	1440	1440	1440
UPS Rated Load (%)	99.8	99.8	99.8
5% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	71.3
Cable Length Difference (%)	0	0	5
UPS Bypass Current (Arms)	1435	1435	1450
UPS Rated Load (%)	99.4	99.4	100.5
10% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	67.5
Cable Length Difference (%)	0	0	10
UPS Bypass Current (Arms)	1430	1430	1461
UPS Rated Load (%)	99.1	99.1	101.2
15% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	63.8
Cable Length Difference (%)	0	0	15
UPS Bypass Current (Arms)	1425	1425	1471
UPS Rated Load (%)	98.7	98.7	101.9
20% Bypass Path Length Difference			
UPS	**UPS #1**	**UPS #2**	**UPS #3**
Bypass Path Cable Length (ft)	75	75	60
Cable Length Difference (%)	0	0	20
UPS Bypass Current (Arms)	1420	1420	1482
UPS Rated Load (%)	98.4	98.4	102.7

Note: *Shaded cells indicate unit is loaded above Liebert EXL S1 110% continuous overload capability at 30°C.*

Field Results

Our experience deploying distributed bypass parallel UPS systems has shown that it is very difficult to match impedances between modules without sharing inductors due to the variables involved in the bypass path (cabling, switchgear busbar and breakers, etc.). For example, a customer installed two parallel Liebert EXL S1 1200 kVA distributed bypass modules. The bypass cable lengths were carefully controlled. UPS #1 had a bypass cable length of 94.7 feet, and UPS #2 had a bypass cable length of 93.25 feet. The percentage difference is equal to:

$$\frac{|L_1 - L_2|}{\left(\frac{L_1 + L_2}{2}\right)} x100\% = \frac{|94.7 - 93.25|}{\left(\frac{94.7 + 93.25}{2}\right)} x100\% = \frac{1.45}{93.975} x100\% = 1.54\%$$

Referring to Table 11, for a Liebert EXL S1 1200 kVA distributed bypass system without sharing inductors, given a 100-foot bypass path we would expect a 1.54% difference in cable length to yield a load sharing difference of less than 5%. However, during commissioning at 100% load on bypass, UPS #1 was loaded to 94% and UPS #2 was loaded to 106% (12% load sharing difference). It was found that due to the switchgear configuration there was a 3.5-foot length of bussing between the paralleled UPS modules that accounted for the additional impedance and consequently the additional imbalance in load sharing.

The commissioning agent in this case raised a concern because UPS #2 was loaded to 106%. Had the customer elected to order sharing inductors with the Liebert EXL S1 modules, the load sharing on bypass would have been within 1%, and this issue during commissioning would have been avoided.

Recommendations

The impedances of the bypass paths need to be controlled for paralleled distributed static switch systems. When operating on bypass, load sharing is a function of impedance differences between each unit's bypass path.

Cabling impedances can be controlled by providing similar lengths of cable to and from each UPS module. The cabling impedance for a parallel system should be matched as closely as possible. Vertiv recommends carefully controlling the cabling differences so that the maximum difference does not exceed 5% of total length. In addition to cabling impedance, the impedance differences caused by elements in the input and output switchgear (busbar, BIB, MOB) must be taken into consideration to calculate the total impedance for each bypass path.

The sharing inductors' impedance compensates for reasonable impedance system mismatches as shown in the tables within this document. For certain Liebert large UPS sharing inductors are required for distributed bypass capacity systems and recommended for 1+1 redundant systems. Furthermore, if the total planned system load exceeds more than 85% per module, Vertiv recommends installing bypass sharing inductors. These minimize the chance of an overload situation when the UPS system operates at full capacity.

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