Direct Current (DC)

Study/Report

Cyclone Generation Substation

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Introduction

The purpose of the DC study is to find the DC load required for the substation to adequately size the battery for both normal operation and for emergency outages. To do the DC study, the DC loads are analyzed over an 8-hour period. The DC loads require items such as the breaker trip coils, the emergency lighting, and the relays. Each item is determined to be active for a certain period during the 8-hour period. After analyzing the current draw that each of DC loads requires, the system can be adequately sized, and a DC battery bank can be configured to handle the load. The worst-case tripping scenario is when AC power is lost, output of the battery charger is interrupted, and the load on the DC system exceeds the maximum output of the battery charger. Through this study, the system is sized to try and handle these situations.

System Design Criteria

Battery Cells

The number of cells (n_{cells}) for the battery can be calculated by the following equation where V_{max} is the maximum system voltage specified to be 140VDC, and V_{charge} is the maximum charge voltage per cell of 2.33VDC.

$$n_{cells} = \frac{V_{max}}{V_{charge}}$$

The number of cells equates to be 60; with this value, the minimum cell voltage (V_{cell}) is 1.75V/cell which is calculated by the following equation where V_{min} is the minimum battery voltage specified to be 105V.

$$V_{cell} = \frac{V_{min}}{n_{cells}} \text{ (V/cell)}$$

Assumed Derating Factors

When sizing a battery, various factors used in the calculations account for the lowest possible temperature, the age, and a design margin; these factors are shown in the following table.

Table 2-1 Battery Correction Factors

Correction Factor	Multiplying Factor
Temperature (Assuming 55°F is the lowest)	1.15
Age (Accounts for battery instability 80% of life)	1.25
Design Margin (Accounts for unexpected future loads)	1.10

Load Classifications

The introduced worst-case scenario: The worst-case tripping scenario is when AC power is lost, output of the battery charger is interrupted, and the load on the DC system exceeds the maximum output of the battery charger.

Table 3-1 First Minute Loads (Load L1, Time = 1 minute)

Quantity	Device	DC Load Current (A)	Total (A)
6	138 kV Breaker Trip Coil #1 (Trip)	12	72
1	69 kV Breaker Trip Coil #1 (Trip)	12	12
1	138 kV MOAB	8	8
		Total =	92 A

The continuous load is primarily made up of relay loads and devices to be continuously energized throughout the 8-hour interval. The table below shows the continuous current and each of the comprising items including future equipment are shown in Appendix A.

Table 3-2 Continuous Loads (Load L2, Time = 480 minutes)

Quantity	Device	DC Load Current (A)	Total (A)
9	Relay & Meter Load	0.2	1.8
1	Transformer 587	0.044	0.044
1	Transformer 58	0.0496	0.0496
1	Transformer 587T	0.184	0.184
		Total =	2.0776 A

Emergency lighting loads shown in the following table are only required to operate for the last half of the 8-hour period.

Table 3-3 Momentary Loads (Load L3, Time = 240 minutes)

Quantity	Device	DC Load Current (A)	Total (A)
6	Emergency Lighting	0.256	1.536
		Total =	1.6A

The following four tables assume that the transformer fault and failed breaker issues have been resolved and the affected part of the substation can be re-energized. Following the re-energization, it is assumed the station AC service issue is resolved and the 8-hour period concluded.
The DC loads required when the substation is returning to normal operating condition are starting motors and closing the breaker trip coils.

Load L4 in Table 3-4 consists of closing the breaker trip coils.

Table 3-4 Momentary Loads (Load L4, Time = 1 minutes)

Quantity	Device	DC Load Current (A)	Total (A)
7	138 kV and 69 kV Breaker Trip Coil #2 (Close)	1.9	13.3
		Total =	13.3 A

Load L5 in Table 3-5 consists of starting the breaker motors.

Table 3-5 Momentary Loads (Load L5, Time = 1 minutes)

Quantity	Device	DC Load Current (A)	Total (A)
7	Start Breaker Motors	9.8	68.6
		Total =	68.6 A

Battery Sizing

Battery Capacity and Duty Cycle

To calculate the total number of amp-hours required of the battery, the 480-minute time frame can be divided into periods where each one can be expressed as a function equal to the total amperes consumed in that time frame. The integral of these piecewise functions over the entire time frame yields the total amp-hours. The following table represents this.

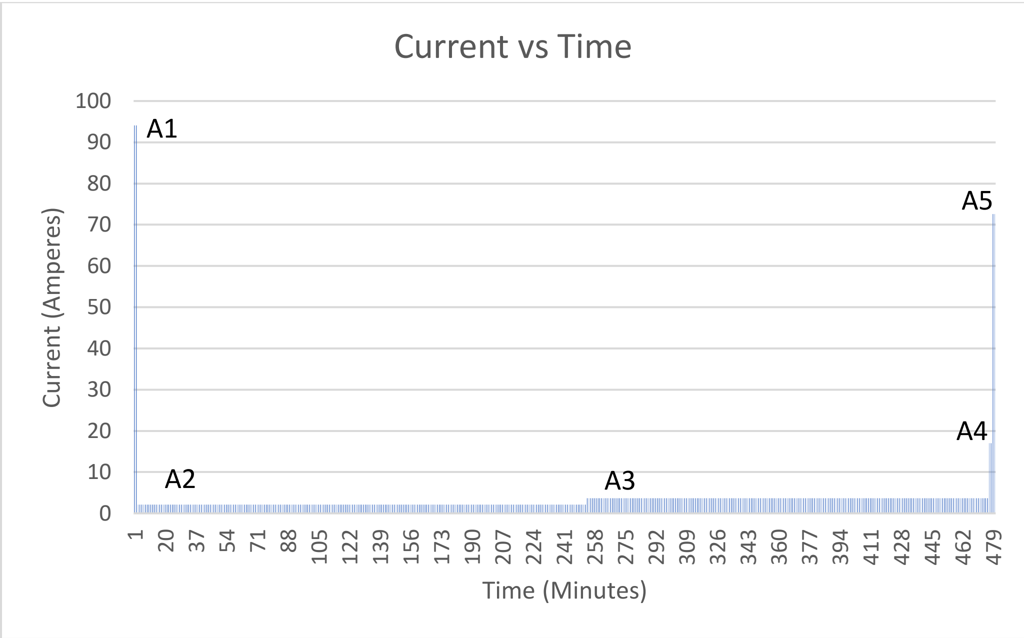
Table 4-1 Total Amp Hours

Period	Loads	Total Amperes	Duration	Amp-Hours
A1	L1+L2	94.1	1	1.57
A2	L2	2.1	239	8.27
A3	L2+L3	3.7	227	13.67
A4	L2+L3+L4	17	1	0.28
A5	L2+L3+L5	72.6	1	1.20

Total= 25.43Ah

From the previous Table 4-1, a duty cycle can be shown as the following figure.

Figure 4-1 Load Profile



Battery Positive Plates

IEEE Standard 485 goes into detail on how to calculate the number of positive plates required of the battery. To do this, the load profile shown in Figure 4-1 used in conjunction with the current per positive plate required to bring the batteries' voltage to 1.75 per cell in a specified amount of time are required. The latter is provided by the battery manufacturer and can be referenced in Appendix B. The following Figure 4-2 illustrates how the largest positive plate size can be found. By using the multiplying factors from Table 2-1, the calculated number of positive plates equates to 3.96, which can be rounded up to 4. The total number of plates for the battery can be calculated by the following equation.

$$total\ number\ of\ plates = 1 + (2 * number\ of\ positive\ plates)$$

The total number of plates equates to nine. The Enersys battery EC-9M will be able to supply the substation considering that the rated capacity of the battery is 365Ah (See Appendix B for Enersys battery lifetime), and the required amount should not exceed 26Ah.

Figure 4-2 Battery Sizing Spreadsheet:

Period	Load (A)		Change in Load (A)		Duration of Period (min)		Time to End of Section (min)		Capacity @ Time/Rate (Amps/Time) or (6B) k Factor(KT)	Required Section Size (3) + (6A) = Postove Plates Or(3) x(6B) = Rated Amp Hrs	
	Amperes		Amperes		Minutes		Minutes			Postive Value	Negtive Value
Section 1- First periods only - If A2 greater than A1, go to Section 2.											
1	A1=	94.0776	A1-0=	94.0776	M1 =	1	T=M1 =	1	0.768421053	72.29	
											Sec (1) Total = 72.29
Section 2- First two periods only - If A3 greater than A2, go to Section 3.											
1	A1=	94.0776	A1-0=	94.0776	M1 =	1	T=M1+M 2 =	240	4.802631579	451.82	
2	A2=	2.0776	A2-A1	-92	M2 =	239	T=M2 =	239	4.802631579		-441.84
											Sec (2) Total = 9.98
Section 3- First three periods only - If A4 greater than A3, go to Section 4.											
1	A1=	94.0776	A1-0 =	94.0776	M1 =	1	T =M1+M2 +M3 =	467	7.913043478	744.44	
2	A2=	2.0776	A2-A1 =	-92	M2 =	239	T =M2+M3 =	466	7.913043478		-728
3	A3=	3.6136	A3-A2 =	1.54	M3 =	227	T=M3 =	227	4.802631579	7.4	
											Sec (3) Total = 23.84
Section 4- First four periods only - If A5 greater than A4, go to Section 5.											
1	A1=	94.0776	A1-0 =	94.0776	M1 =	1	T=M1+M 2+M3+M 4 =	468	7.913043478	744.44	
2	A2=	2.0776	A2-A1 =	-92	M2 =	239	T=M2+M 3+M4 =	467	7.913043478		-728
3	A3=	3.6136	A3-A2 =	1.54	M3 =	227	T=M3+M 4 =	228	4.802631579	7.4	
4	A4=	16.9136	A4-A3 =	13.3	M4 =	1	T=M4 =	1	0.768421053	10.22	
											Sec (4) Total = 34.06
Section 5- First five periods only - If A6 greater than A5, go to Section 6.											
1	A1=	94.0776	A1-0 =	94.0776	M1 =	1	T=M1+M 2+M3+M 4+M5 =	469	7.913043478	744.44	
2	A2=	2.0776	A2-A1 =	-92	M2 =	239	T=M2+M 3+M4+M 5 =	468	7.913043478		-728
3	A3=	3.6136	A3-A2 =	1.54	M3 =	227	T=M3+M 4+M5 =	229	4.802631579	7.4	
4	A4=	16.9136	A4-A3 =	13.3	M4 =	1	T=M4+M 5 =	2	0.768421053	10.22	
5	A5=	72.2136	A5-A4 =	55.3	M5 =	1	T=M5 =	1	0.768421053	42.49	
											Sec (5) Total = 76.55
		Maximum Section Size is Sec (5) = 76.55						US	76.55		
		Random Section Size = 0						Temperature	1.15		
								Design Margin	1.1		
		Uncrrocted Size		US = 76.55				Aging factor	1.25		
								Postive value	121.04		

Battery Charger Sizing

When sizing the battery charger, the capacity (A) in amps can be found by the following equation where L is the continuous load being 2.1 Amps, C is the ampere hours emergency discharge which is the 365Ah battery rating of the Enersys (EC-9M), H is the number of hours recharge time assumed to be 24 hours, and the 1.1 constant is a factor accounting for the efficiency of lead acid cells.

$$A = L + \frac{(1.1 * C)}{H}$$

The charger capacity is calculated to be 18.83 Amps, and therefore, the next larger size provided by Hindle Power capable of handling 20 Amps will be sufficient for the substation.

Conclusion

This study was performed by evaluating the DC loads required for the Cyclone Substation to determine the appropriate battery bank size and the DC battery charger size. The study shows that in an 8-hour period, the substation's DC load is a total of 26Ah. Through this study, it has been found that 60 battery cells and a battery charger capable of handling 20 Amperes will be sufficient for the substation.

References

[1] IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Application, IEEE Standard 485-1997 (R2003)

[2] Schweitzer website for relay continuous ampacity, www.selinc.com

Appendix A – Continuous Load Profile

138kV

Quantity	Relay Description	Power	Current	Total Current
3	SEL-352(BFR/B1/B2/B3)		0.2	0.6
1	SEL-311L(PR/R)		0.2	0.2

69kV

Quantity	Relay Description	Power	Current	Total Current
1	SEL-387(870A/TR1)		0.2	0.2

Transformer

Quantity	Relay Description	Power	Current	Total Current
1	SEL-587(87T/TR1)		0.044	0.044
1	SEL-551(50/TR1)		0.0496	0.0496
1	SEL-587Z(87TH/TR1)		0.184	0.184

Communication & Metering

Quantity	Relay Description	Power	Current	Total Current
2	SEL-321(BU/R)		0.2	0.4
1	SEL-311B(BU/C)		0.2	0.2
1	SEL-351A		0.2	0.2

Total Continuous Load:	2.0776 A

Appendix B – Enersys EC-M Battery Discharge Current

Discharge Rates in Amperes** to 1.75Vpc at 25˚C (77˚F)*

PowerSafe® EC-M cell TYPE*	NOM Ah CAP.[1]	Minutes			Hours									
		1	15	30	1	1.5	2	3	4	5	8	12	24	72
EC-5M	215	253	180	140	100	80	67	52	43	37	27	20	12	6
EC-7M	290	364	266	204	144	113	95	72	59	51	36	27	16	7
EC-9M	365	475	351	269	188	147	122	93	76	65	46	33	20	8
EC-11M	470	594	443	340	239	187	155	118	96	82	58	42	25	11
EC-13M	525	694	511	392	274	214	177	134	109	93	65	47	28	11
EC-15M	620	812	596	455	318	249	207	157	128	110	78	56	33	14
EC-17M	670	925	690	525	364	283	233	176	142	120	84	60	34	14
EC-19M	795	981	741	573	405	318	265	202	165	141	100	72	43	18
EC-21M	850	1068	802	625	443	349	290	220	179	152	106	76	45	18