rpsa
FIRE PROTECTION ENGINEERS

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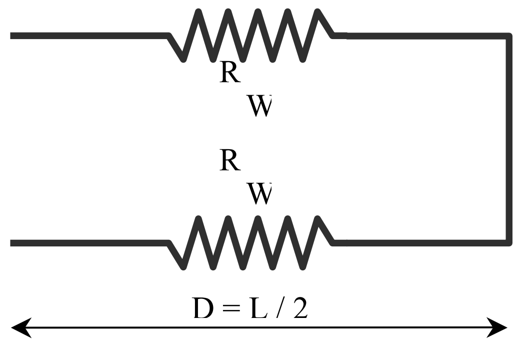
Sample Fire Alarm System Calculations

1. **A fire alarm manufacturer specifies a maximum allowable loop resistance of 50 Ω. What is the maximum allowable distance from the control unit to the last device if a #16 AWG stranded, un-coated copper wire is used? Assume a temperature of 75^{0}C. How does this change if the temperature is 20^{0}C?**



$R_{max} = 50\ \Omega = 2\ R_W\ \ \Omega$

$R_W = R_u\, D\ \ \Omega$

$R_{max} = 50\ \Omega = 2\ R_u\, D\ \ \Omega$

R_u = 4.99 Ω/1000 ft or 0.00499 Ω per handout table for #16 AWG stranded, uncoated copper wire at 75^{0}C

$$D = \frac{R_{max}}{2R_u} = \frac{50}{2(0.00499)} = 5010 = 5000\ \ \text{ft}$$

Part B If T = 20^{0}C calculate the unit resistance, R_u, at the lower temperature (it should be less since resistance is lower at lower temperatures leading to super cooled super conductors):

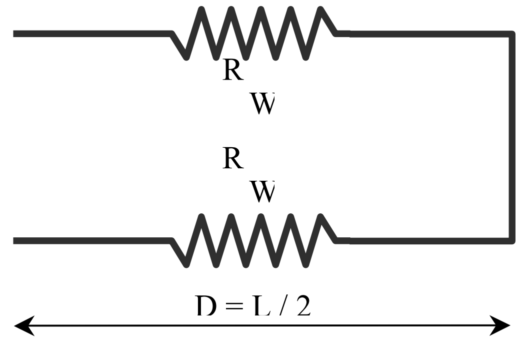
$R_2 = R_1\ [1 +\ \alpha\ (T_2 - 75)]$ where: $\alpha_{Cu} = 0.00323$
$R_2 = 0.00499\ [1 +\ 0.00323\ (20 - 75)]\ \ \Omega/\text{ft}$ or $R_2 = 4.99\ [1 +\ 0.00323\ (20 - 75)]\ \ \Omega/1000\ \text{ft}$
$R_2 = 0.00410\ \ \Omega/\text{ft}$

$$D = \frac{R_{max}}{2R_u} = \frac{50}{2(0.00410)} = 6092 = 6000\ \ \text{ft}$$

2. **If a #24 AWG conductor has a resistance of 25.67 Ω/1000 ft at 200C what is the maximum allowable distance from the control unit to the last device for a system having a maximum allowable loop resistance of 50Ω?**

$$D = \frac{R_{max}}{2R_u} = \frac{50}{2(0.02567)} = 974 = 1000\ \ \text{ft}$$

3. **Plot total loop resistance, R_T, as a function of circuit distance (D = L/2) for 14, 16, 18, 22 and 24 AWG uncoated solid copper wire. Use unit resistances of 3.07, 4.89, 7.77, 16.14, and 25.67 Ω/1000 ft respectfully.**



$R_W = R_u D \quad \Omega$

$R_T = 2\, R_W = 2\, R_u D \quad \Omega$

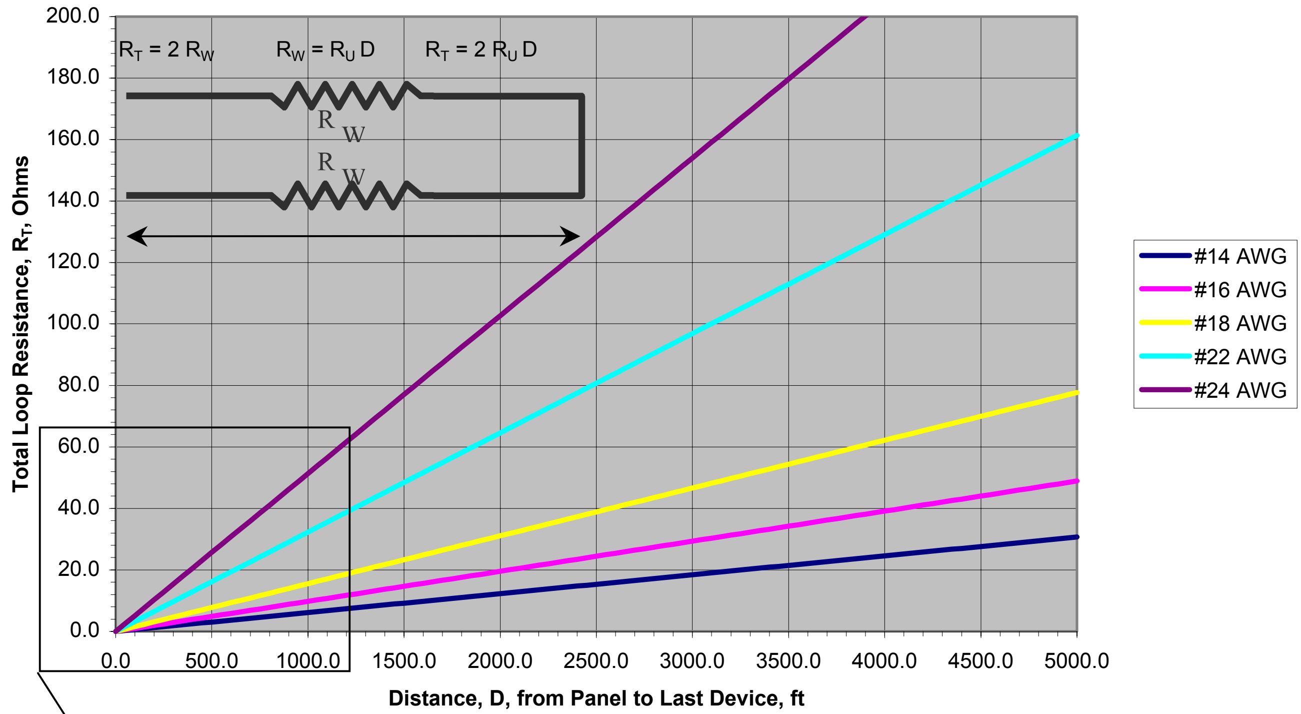
⇛ Plotting R_T as a function of D will result in a straight line having a slope of $2R_u$ and a Y intercept of 0.

Also, a test of the data or the plot is:
When L = 1000 ft, $R_T = 1000\, R_u \quad \Omega$. This occurs at D = L/2 = 500 ft So, at D = 500 ft we should see $R_T = 1000\, R_u \quad \Omega$.

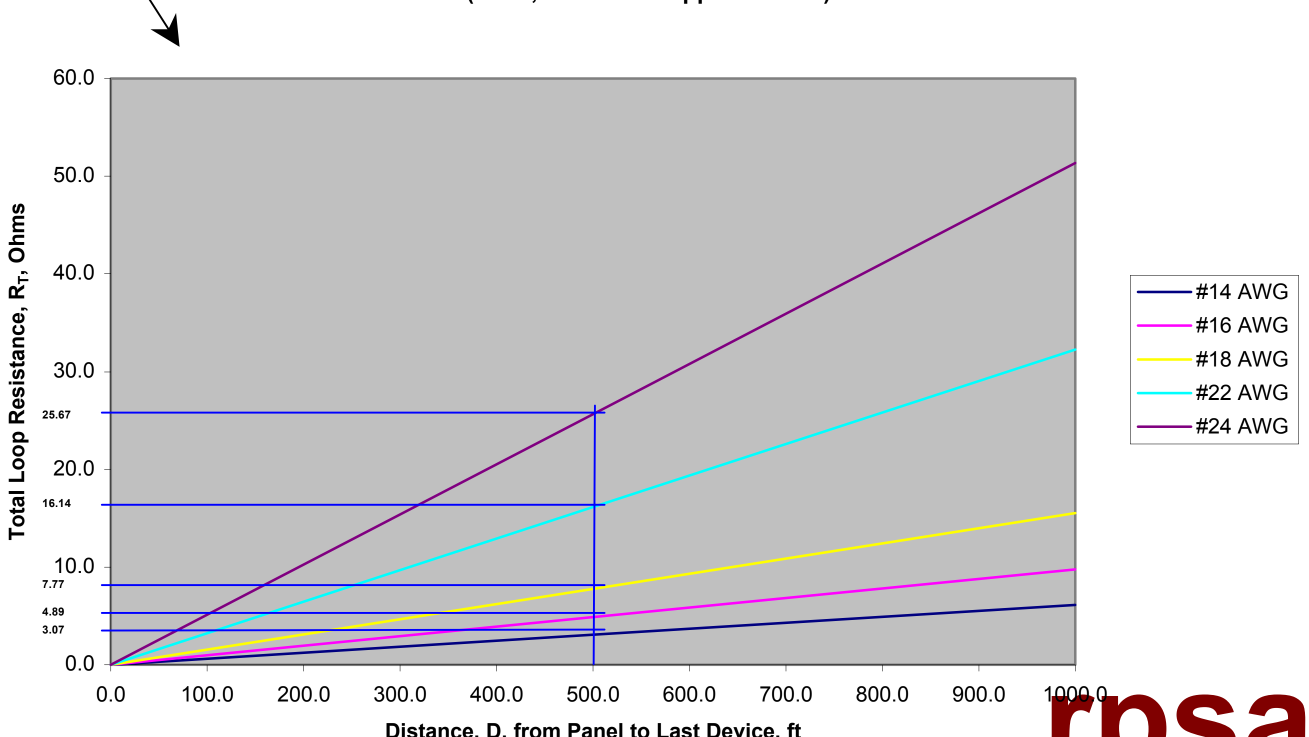
D, ft	#14 AWG	#16 AWG	#18 AWG	#22 AWG	#24 AWG
0.0	0.0	0.0	0.0	0.0	0.0
500.0	3.070	4.890	7.770	16.140	25.670
1000.0	6.140	9.780	15.540	32.280	51.340

See plots on next page.

Loop Resistance
(Loop is 2 x D)
(Solid, uncoated copper at 75^{0}C)

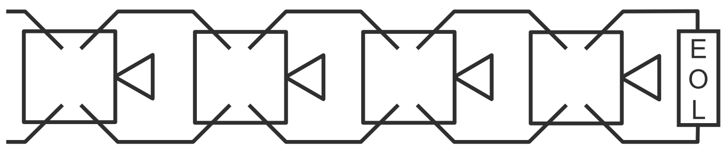


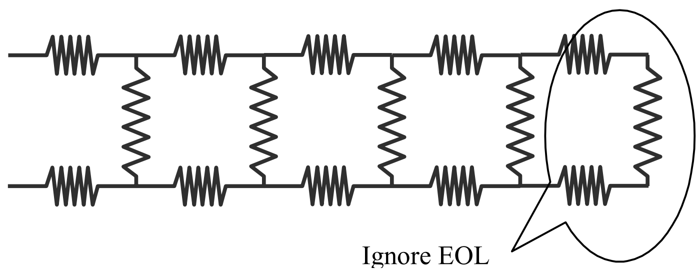
Loop Resistance
(Loop is 2 x D)
(Solid, uncoated copper at 750C)

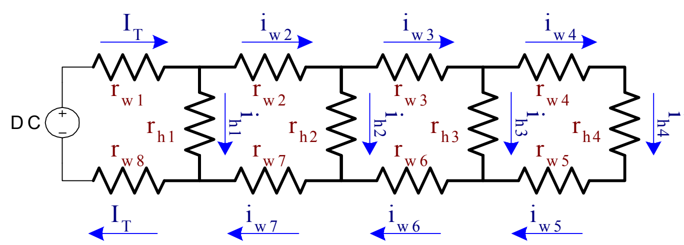


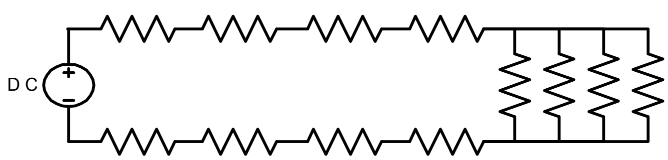
4. **A notification appliance circuit (NAC) serves four horns located in a remote portion of a building. The circuit is approximately 400 feet from the panel to the last appliance and is wired using #16 AWG stranded, uncoated copper wire. Each appliance is rated to draw 0.05 amps at a nominal 24 volts DC. The appliances are rated to produce 78 dBA at 3 meters as long as the voltage is no less than 22 nor more than 29 VDC. The fire alarm power supply is rated at a nominal 24 VDC. Calculate the voltage across the horns and determine if it is sufficient to operate the horns at the rated sound pressure level (SPL). Simplified calculation methods are permitted. Is a larger (smaller AWG number) wire size needed? If so, what size? Can a smaller (larger AWG number) wire size be used?**

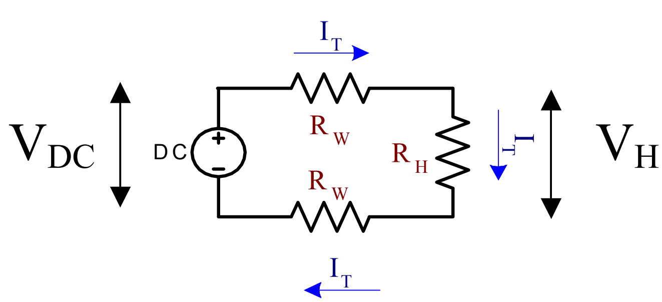
The diagrams below show how the circuit analysis can be simplified.











There are two methods to solve for the voltage across the horns (load) using the simplified circuit diagram. The first assumes that the load will not draw the nominal rated current because they will be operating at a reduced voltage, not their nominal rated voltage. The second method assumes that the current draw by the load will be the nominal even though the reduced voltage will actually result in a smaller current draw.

In addition to the two possible calculation methods, we must choose a starting voltage. Although the nominal voltage of the power supply is 24 VDC, it is reasonable to assume that if it switches to batteries as a secondary power supply, the voltage will decrease or degrade over the required supply time. NFPA 72 and UL require a power supply – even secondary power – to put out no less than 85% of the nominal voltage. Therefore:

V_{DC} = 0.85 x 24 = 20.4 VDC as a starting voltage

SOLUTION # 1

The resistance of each horn is calculated using the nominal voltage and current specified by the manufacturer:

r_h = v/i = 24/0.05 = 480 Ω

The equivalent resistance of 4 horns in parallel is:

$$\frac{1}{R_H} = \frac{1}{r_{h1}} + \frac{1}{r_{h2}} + \frac{1}{r_{h3}} + \frac{1}{r_{h4}} = \frac{4}{480}$$
$$R_H = 120 \ \ \Omega$$

The resistance of each length of wire is:

$$R_W = R_u D = \left(\frac{4.99\Omega}{1000 \text{ ft}}\right) 400 \text{ ft} = 1.996\ \Omega$$

The total resistance of the circuit, R_T, is the sum of all three series resistances:

$R_T = R_W + R_W + R_H$ = 1.996 + 1.996 + 120 = 123.992 Ω

When a voltage of 20.4 VDC is applied across a resistance of 123.992 Ω, how much current flows?

$$I_T = \frac{V_{DC}}{R_T} = \frac{20.4}{123.992} = 0.165 \text{ Amps or 165 mA}$$

The voltage at the load is then:

$V_H = I_T R_H = 0.165(120) = 19.8 = 20$ VDC

In this problem we were told that "The appliances are rated to produce 78 dBA at 3 meters as long as the voltage is no less than 22 nor more than 29 VDC". Therefore, we must be sure that the appliances receive at least 22 VDC. Since 20 < 22 they will not sound at full volume. However, is 22 VDC really the lowest voltage at which they will operate correctly? At the present time, if a manufacturer's specifications list such a range U.L. requires that the horn actually work at 80% of that low number: 0.80 x 22 = 17.6. Therefore, the answer depends on which voltage is really the lowest the horns require to sound at full volume.

If we assume that they really will work at a minimum voltage of 17.6, then the wire size is adequate. So, if I were analyzing a set of conditions such as these, I would conclude they would work. However, for a design or design review we would set a goal with a factor of safety. I think it would be reasonable to use 10 to 20% factor of safety. I would prefer that a proposed circuit not drop below the manufacturer's specified minimum. But if we start with a degraded power supply at 20.4 VDC we are already below the manufacturer's stated minimum of 22 VDC. A 10% factor of safety would require that the voltage not drop below 0.9 x 22 = 19.8 = 20 VDC. The circuit in this situation would just meet that criteria.

SOLUTION # 2

Assume the actual current flow is equal to the nominal current flow:

$I_T = i_{h1} + i_{h2} + i_{h3} + i_{h4} = 4(i_h) = 4(0.05) = 0.2$ A

$V_{DC} - V_W - V_H - V_W = 0$

$V_H = V_{DC} - 2\,V_W$

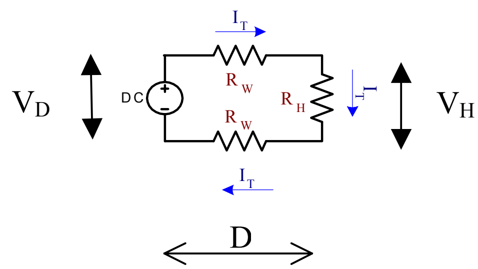
$V_H = 20.4 - 2\,I_T R_W$

$$R_W = R_u D = \left(\frac{4.99\Omega}{1000\text{ ft}}\right) 400\text{ ft} = 1.996\ \Omega$$

$V_H = 20.4 - 2\,(0.2)\,(1.996) = 19.6 = 20$ VDC

5. Using a spreadsheet create a table similar to the following by calculating allowable circuit length (from panel to last appliance) for each combination of amperage and wire size. Use the following: Nominal 24 VDC power supply de-rated to 85% of nominal; 16 VDC required at the end of the circuit (last appliance); #18 and # 16 AWG wire is solid, uncoated copper; #14, #12, and #10 AWG wire is stranded uncoated copper; wire is at 75^{0}C . Calculations and results may be in feet, meters or both.

$$V_{DC} - V_W - V_H - V_W = 0$$
$$V_{DC} - 2V_W - V_H = 0$$
$$V_{DC} - 2I_T R_W - V_H = 0$$
$$V_{DC} - 2I_T R_u D - V_H = 0$$
$$D = \frac{(V_{DC} - V_H)}{2I_T R_u} \text{ ft}$$



In this case we are given V_{DC} = 20.4 VDC and V_H = 16 VDC. The formula for D is placed in each cell of the table with I_T and R_U as the variables.

	18 AWG	16 AWG	14 AWG	12 AWG	10 AWG
	Solid C_u	Solid C_u	Stranded C_u	Stranded C_u	Stranded C_u
	0.00777	0.00489	0.00314	0.00198	0.00124
	Ω/ft	Ω/ft	Ω/ft	Ω/ft	Ω/ft
Amps	Allowable Circuit Length, ft				
0.5	566	900	1401	2222	3548
1.0	283	450	701	1111	1774
1.5	189	300	467	741	1183
2.0	142	225	350	556	887
2.5	113	180	280	444	710
3.0	94	150	234	370	591
3.5	81	129	200	317	507
4.0	71	112	175	278	444
Amps	Allowable Circuit Length, m				
0.5	173	274	427	678	1082
1.0	86	137	214	339	541
1.5	58	91	142	226	361
2.0	43	69	107	169	270
2.5	35	55	85	136	216
3.0	29	46	71	113	180
3.5	25	39	61	97	155
4.0	22	34	53	85	135

6. **Assuming batteries will be used as a secondary power supply, use the attached form to determine what capacity (ampere-hours) batteries would be required for the protected premises fire alarm system. Assume 1/2 of the smoke detectors in alarm at the same time, 70 hours of standby followed by 5 minutes of alarm, and a 20% factor of safety. How might you reduce the required battery size? The system is composed of the following:**

ITEM	DESCRIPTION	STANDBY CURRENT PER UNIT (AMPS)		QTY		TOTAL STANDBY CURRENT PER ITEM (AMPS)
A	FACU	0.200	X	1	=	**0.200**
B	Heat detectors	0.000	X	12	=	**0.000**
C	Photoelectric Smoke Detectors	0.000100	X	100	=	**0.010000**
D	Normally energized control relays	0.02	X	10	=	**0.20**
E	Normally de-energized relays	0.00	X	5	=	**0.00**
F	Strobe Lights (15 candela)	0.000	X	20	=	**0.000**
G	Strobe Lights (110 candela)	0.000	X	40	=	**0.000**
H	Horns	0.000	X	20	=	**0.000**
		TOTAL SYSTEM STANDBY CURRENT (AMPS)				**0.41**

ITEM	DESCRIPTION	ALARM CURRENT PER UNIT (AMPS)		QTY		TOTAL ALARM CURRENT PER ITEM (AMPS)
A	FACU	0.600	X	1	=	**0.600**
B	Heat detectors	0.000	X	12	=	**0.000**
C	Photoelectric Smoke Detectors	0.050	X	50	=	**2.500**
D	Normally energized control relays	0.00	X	10	=	**0.00**
E	Normally de-energized relays	0.02	X	5	=	**0.10**
F	Strobe Lights (15 candela)	0.060	X	20	=	**1.200**
G	Strobe Lights (110 candela)	0.218	X	40	=	**8.720**
H	Horns	0.040	X	20	=	**0.800**
		TOTAL SYSTEM ALARM CURRENT (AMPS)				**13.92**

REQUIRED STANDBY TIME (HOURS)		TOTAL SYSTEM STANDBY CURRENT (AMPS)		REQUIRED STANDBY CAPACITY (AMP-HOURS)
0.41	X	70	=	28.7

REQUIRED ALARM TIME (HOURS)		TOTAL SYSTEM ALARM CURRENT (AMPS)		REQUIRED ALARM CAPACITY (AMP-HOURS)
13.92	X	0.083	=	1.155

REQUIRED STANDBY CAPACITY (AMP-HOURS)		REQUIRED ALARM CAPACITY (AMP-HOURS)		TOTAL REQUIRED CAPACITY (AMP-HOURS)
28.7	+	1.155	=	29.86

TOTAL REQUIRED CAPACITY (AMP-HOURS)		OPTIONAL FACTOR OF SAFETY		ADJUSTED BATTERY CAPACITY (AMP-HOURS)
29.86	X	1.2	=	35.8

Minimum 36 AH battery required.

To reduce the battery size try changing the normally energized relays to ones that are energized on alarm.

ITEM	DESCRIPTION	STANDBY CURRENT PER UNIT (AMPS)		QTY		TOTAL STANDBY CURRENT PER ITEM (AMPS)
A	FACU	0.200	**X**	1	=	**0.200**
B	Heat detectors	0.000	**X**	12	=	**0.000**
C	Photoelectric Smoke Detectors	0.000100	**X**	100	=	**0.010000**
D	Normally energized control relays	0.02	**X**	0	=	**0.00**
E	Normally de-energized relays	0.00	**X**	15	=	**0.00**
F	Strobe Lights (15 candela)	0.000	**X**	20	=	**0.000**
G	Strobe Lights (110 candela)	0.000	**X**	40	=	**0.000**
H	Horns	0.000	**X**	20	=	**0.000**
		TOTAL SYSTEM STANDBY CURRENT (AMPS)				**0.21**

ITEM	DESCRIPTION	ALARM CURRENT PER UNIT (AMPS)		QTY		TOTAL ALARM CURRENT PER ITEM (AMPS)
A	FACU	0.600	**X**	1	=	**0.600**
B	Heat detectors	0.000	**X**	12	=	**0.000**
C	Photoelectric Smoke Detectors	0.050	**X**	50	=	**2.500**
D	Normally energized control relays	0.00	**X**	0	=	**0.00**
E	Normally de-energized relays	0.02	**X**	15	=	**0.30**
F	Strobe Lights (15 candela)	0.060	**X**	20	=	**1.200**
G	Strobe Lights (110 candela)	0.218	**X**	40	=	**8.720**
H	Horns	0.040	**X**	20	=	**0.800**
		TOTAL SYSTEM ALARM CURRENT (AMPS)				**14.12**

REQUIRED STANDBY TIME (HOURS)		TOTAL SYSTEM STANDBY CURRENT (AMPS)		REQUIRED STANDBY CAPACITY (AMP-HOURS)
0.21	X	70	=	14.7

REQUIRED ALARM TIME (HOURS)		TOTAL SYSTEM ALARM CURRENT (AMPS)		REQUIRED ALARM CAPACITY (AMP-HOURS)
14.12	X	0.083	=	1.172

REQUIRED STANDBY CAPACITY (AMP-HOURS)		REQUIRED ALARM CAPACITY (AMP-HOURS)		TOTAL REQUIRED CAPACITY (AMP-HOURS)
14.7	+	1.172	=	15.87

TOTAL REQUIRED CAPACITY (AMP-HOURS)		OPTIONAL FACTOR OF SAFETY		ADJUSTED BATTERY CAPACITY (AMP-HOURS)
15.87	X	1.2	=	19

Battery requirement can be reduced to minimum 19 AH battery required.