IALA GUIDELINE

G1067-1
TOTAL ELECTRICAL LOADS OF AtoN

Edition 2.1

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DOCUMENT REVISION

Revisions to this document are to be noted in the table prior to the issue of a revised document.

Date	Details	Approval
May 2009	First issue	Council 45
December 2017	All sections reviewed and updated following the realignment of the documentation to the standards. Updated to reflect developments in technology and clarification of calculations.	Council 65
July 2022	Edition 2.1 Editorial corrections.	

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1. INTRODUCTION

When planning to power an existing or new Marine Aids to Navigation (AtoN), it is highly advisable to choose the lowest consumption equipment to meet the operational requirements. Powered equipment to be considered with respect to consumption and efficiency include but are not limited to:

- Light source and optic equipment
- Radio AtoN
- Sound signals
- Control and monitoring system

2. HOW TO USE THIS GUIDELINE

This document is part of a set of guidelines and needs to be read in conjunction with the following documents:

- IALA Guideline *G1067-0 Selection of Power Systems for AtoN and Associated Equipment*
- IALA Guideline *G1067-2 Power Sources*
- IALA Guideline *G1067-3 Electrical Energy Storage for AtoN*

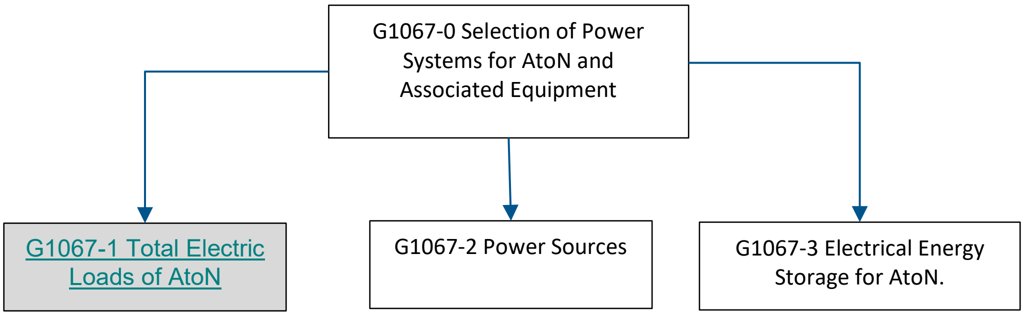

Figure 1 Overview of the Guideline structure

3. AtoN LOAD OVERVIEW

When determining the total electrical loads for a system, the following questions need to be answered:

- What needs power? - Identification of equipment and on which system.
- How much power? - Identification of the power consumption for each item in each mode of operation.
- How long is it needed? - Any character, duty cycle, during the periods of operations.
- When is it needed? - Daily, seasonal, weather dependant, traffic dependant and on-demand.

The first task in establishing the total electrical load is to estimate the length of time that each load will be operating. Estimating the length of time that a load is operating should be as accurate as possible, noting that if the AtoN is operating only at night, the length of operating time will vary with the seasons.

A small error in estimating load operating time will be cumulative day after day, magnifying the error over the year. This could be critical for installations at high latitudes. If detailed information is not available, the 'worst case' situation can be considered and the system designed for the longest winter night.

The design should ensure that switching devices turn the light on and off at the correct light levels to match the light-on periods calculated. At higher latitudes, there will be a marked seasonal effect on light-on periods.

It is advisable to consider the effect of a failure in one of the AtoN subsystems with regards to the power consumption of a complex AtoN system. Manufacturers should be encouraged to disclose the most probable failure modes and corresponding power consumption scenarios for supplied equipment.

3.1. QUIESCENT LOAD

The quiescent load is the power requirement of a piece of equipment which is idle, listening or monitoring. Transceivers generally have different load profiles when transmitting and when listening. Charge controllers typically consume more power during the day when the power electronics are energised, than at night or when the battery is fully charged.

3.2. DAY/NIGHT LOADS

Daytime or night time loads can vary significantly from season to season. As an example, a light operating at night at 58 degrees North latitude will be illuminated for approximately 18 hours in December and less than 6 hours in June. These differences can have a significant impact on the size of the power source and the electrical energy storage system. Energy efficiency becomes very important in the higher latitudes. For example, 5 mA idle current for a lantern during daytime does not seem much, but for an autonomy period of 60 days about 7 Ah extra capacity is needed in the battery to allow for the idle current.

3.3. POWER DEMAND VARIATION

Power demand on AtoN sites is effected by numerous factors including but not limited to:

- Temperature region
- Daytime/night time loads
- Latitude
- Weather conditions
- Equipment type and mode of operation
- Peak demand

Temperature extremes and voltage fluctuations can also cause variation in the power requirements of loads. A resistive load will draw more energy as the voltage increases. Many components exhibit this characteristic.

Loads that operate during the daytime at photovoltaic powered aids to navigation will typically be exposed to higher system voltages as the array tries to recharge the battery. Components used should be able to handle these variations. The power consumption of the loads must be determined at the typical operating voltages.

In areas where there is often heavy cloud cover or fog the correct threshold setting of light switch-on and switch-off is important. If threshold for turn off is too high, it is possible that on a cloudy day the turn off of the light is delayed many hours from the intended time, which causes battery depletion.

Loads that operate both day and night may see different system voltages and thus average power consumption may need to be calculated to accurately predict system performance. Likewise, the power consumption of some loads varies as the temperature varies from ambient conditions.

The load demands at different latitudes will need to be adjusted to take into account the different night time periods; a major consideration at some latitudes must be the seasonal variation of load.

An accurate load profile from the vendor and an idea of the operating conditions are very helpful in estimating the actual power requirements; actual measurements at the AtoN location (or calculated) are vital to confirming the adequacy of the power system design.

As well as the above factors, careful design of the distribution infrastructure needs to be considered to ensure that aggregated instantaneous loads are met, without any impact on the equipment operation. This is becoming ever more critical for modern electronic and radio AtoN.

4. DAILY AND SEASONAL LOAD VARIATIONS

NOTE: This section is to be read in conjunction with IALA Guideline G1038 - Methods and Ambient Light Levels for the Activation of AtoN Lights.

4.1. COMPUTATION OF A DAILY LOAD

The most important aspect of a primary or secondary battery powered system design is the calculation of the daily energy load (E_{DL}), for each item of equipment. This is usually expressed as watt-hours per day (Wh/day).

$$E_{DL} = Load \times Duration\ of\ Operation\ per\ Day$$

Equation 1 Calculation of the daily load

Where:

E_{DL} is the daily energy load, measured in Watt-hours (Wh)

Load is the power consumption of the equipment measured in Watts (W)

Duration is duration of operation per day, measured in hours (h)

4.1.1. DUTY CYCLE

The above energy daily load calculation can be modified by the following formula, if the load is cycled.

$$Duty\ Cycle = \frac{Time\ ON}{Time\ ON + Time\ OFF}$$

Equation 2 Duty cycle

4.2. SEASONAL VARIATION OF DAILY LOADS

Loads that are daylight controlled, that operate only during the day or only at night take more work to predict. Because the number of hours of daylight changes daily, the load will change daily. Most simple power system designs are based on the highest daily power consumption. In the Northern Hemisphere, this occurs around December 21 for night-time loads and June 21 for daytime loads. The dates are reversed for the Southern Hemisphere. A more precise method is to create a computer program, or use a computer spreadsheet, to calculate the load for each day of the year, and then assess energy balance during the most demanding period of operation.

Assuming that the loads switch on or off at sunrise or sunset, the first step in determining daily loads is to calculate the number of hours of daylight or, conversely, the number of hours of darkness. The number of hours of daylight in a day, $H_{daylight}$, is defined to be the number of hours between sunrise and sunset. The number of hours of darkness, $H_{darkness}$, is defined to be the number of hours between sunset and sunrise. The following equation can be used to calculate the number on hours of daylight. It should be noted that the equation is an approximation that is most accurate at the equator. The approximations has been adopted due to the fact that the Earth is an oblate spheroid and to account for the effects of refraction of the atmosphere. There are a number of alternative methods of calculating daylight hours available, these can be used but the results should be checked against the equations below or the results of measurement.

If all calculations are done in degrees then:

$$H_{daylight} = \left(\frac{2}{15}\right) arc\ cos\left[\frac{-0.0151 - sinL \times sinD}{cosL \times cosD}\right]$$

Equation 3 Hours of daylight (degrees)

where :

$H_{daylight}$ is the number of hours between sunrise and sunset.

L is the latitude of site, positive values for northern latitudes, and negative values for southern latitudes.

D is the sun's declination, positive values for northern declinations, negative values for southern declinations.

Note: The number -0.0151 is a number that has been derived to express the number hours of daylight that incorporates both the semi diameter and the refraction affects.

4.2.1. NOTE ON DECLINATION:

The sun's declination ranges between 23.45° S (-23.45°) and 23.45° N (+23.45°). The day with the largest number of hours of darkness occurs on the date of the winter solstice. The declination on the date of the northern hemisphere's winter solstice is 23.45° S (-23.45°). The declination on the date of the southern hemisphere's winter solstice is 23.45° N (+23.45°).

To determine D for use in Equation 3 and Equation 4, three different scenarios need to be considered depending on the Julian date to be used. The sun's declination (D) in degrees can be approximated as:

D = 23.45 sin(1.008(n-80)) for n = 1 - 80

D = 23.45 sin(0.965(n-80)) for n = 81 - 266

D = -23.45 sin(0.975(n-266)) for n = 267 - 365

Where n is the Julian date and all calculations are done in degrees.

4.2.2. NOTE ON HIGH LATITUDES

The above theoretical calculation (Equation 3 and Equation 4) is not mathematically possible for latitudes greater than 65.6° during certain periods of the year, whereby the following portion of the calculation must be replace with the value of 1 or -1. So the following part of the $H_{daylight}$ equations (see Equation 3 and Equation 4):

$$\left[\frac{-0.0151 - sinL \times sinD}{cosL \times cosD}\right]$$

will be less than -1 for a portion of the year and greater than +1 for a different portion of the year. During these portions of the year for $H_{daylight}$ becomes as follows:

If $\left[\frac{-0.0151 - sinL \times sinD}{cosL \times cosD}\right] < -1$ then $H_{daylight}$ = 24 (the sun does not set).

The number of hours between sunset and sunrise, $H_{darkness}$, can be readily calculated.

If $\left[\frac{-0.0151 - sinL \times sinD}{cosL \times cosD}\right] > -1$ then $H_{daylight}$ = 0 (the sun does not rise).

using $H_{daylight}$:

$$H_{darkness} = 24 - H_{daylight}$$

Equation 4 Hours of darkness

4.2.3. HOURS OF OPERATION

The hours of operation usually correspond to the hours of darkness ($H_{darkness}$), but extended operation hours occur due to National regulation for example. As such, a correction factors can be inserted easily.Modifiers to $H_{darkness}$

This is a theoretical figure for when the Marine Aids to Navigation switched on and off. However, in practice, this is achieved with a photocell. The real figure could exceed this value, subject to climatic conditions, local conditions, shading and photocell adjustment. To account for these variations, particularly at high latitudes, a safety factor may be applied to the equation.

5. ACTUAL LOADS

5.1. INCANDESCENT LIGHT SOURCES

NOTE: Under Light Sources, only lamps are discussed, LED are discussed in section 5.2. The inclusion of other sources will need to be examined and if required calculation should be amended.

The most common load to all aids to navigation is the light. Lamps are classified by voltage and lamp current or power. Lamps that receive regulated output voltage from a flasher or voltage regulator consume the rated or calculated current. For example, a 12 volt, 100 watt incandescent lamp will consume 8.33 amperes at rated voltage. This rating applies only to incandescent lamps operating fixed-on. Flashed lamps, while saving power during eclipse, draw more than the rated current during flash because of the cold current surge of the filament as shown in Figure 2.

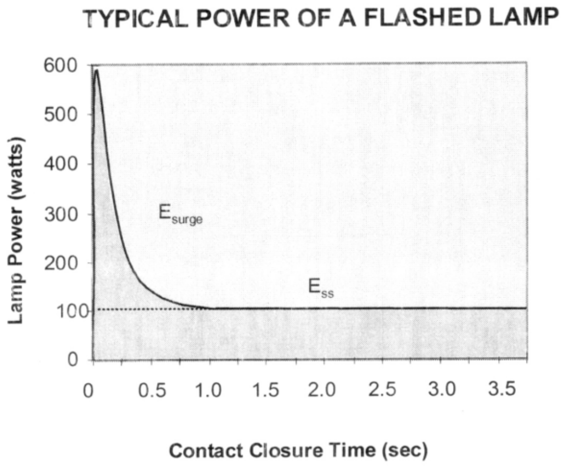

Figure 2 Typical power of a flashed lamp

The area under the curve represents energy (E). The energy consumed during one flash (E_1) can be divided into 2 parts:

$$E_1 = E_{surge} + E_{ss}$$

Equation 5 Total energy for one flash

where:

E_1 is energy consumed during one flash.

E_{surge} is the portion of the consumed energy associated with the surge. This is represented by the upper area of the curve is in Figure 3.

E_{ss} is the energy associated with *steady state* power. This is represented by the rectangular area in Figure 3.

Consider E_{surge} : for any given lamp; E_{surge} can be considered a constant. A plot of the surge factor for common marine aids to navigation incandescent lamps in shown in Figure 3.

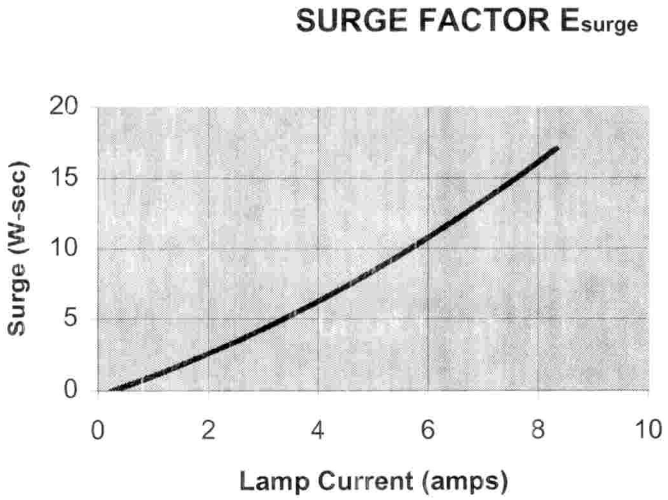

Figure 3 Surge Factor E_{surge}

E_{surge} can be approximated by the following equation:

$$E_{surge} = 0.1019 \times I^2 + 1.24 \times I - 0.3341$$

Equation 6 Approximation of E_{surge}

where:

I is the lamp current in Amps

E_{surge} is in watt-seconds

Now consider E_{ss}:

$$E_{ss} = P_{ss} \times T_{flash}$$

Equation 7 Energy associated with steady state *power*

where:

P_{ss} is the lamp's steady state power requirements (watts)

T_{flash} is the flash length (s)

E_{ss} is in watts-seconds

To find the energy consumed in a day (daily load) multiply by the number of flashes in one day:

$$E_{DL} = E_1 \times \frac{H}{T_{period}}$$

Equation 8 Daily energy load from flash energy consumption

where:

E_1 is the energy consumed per flash in watt-sec where $E_1 = E_{Surge} + E_{SS}$

H is the hours of operation of the light per day (hours)

T_{period} is the flash period (on plus off time) of the light (sec)

Note that E_{DL}, the daily load, conveniently comes out in Wh/day

Combining Equation 6 and Equation 7 into Equation 8 we get:

$$E_{DL} = [E_{surge} + E_{ss}] \times \frac{H}{T_{period}}$$

Equation 9 Total Daily energy from flashed lamp.

The calculations listed above for lamp energy are approximations based on empirical data and may be used in lieu of actual measurements. Suppliers of lamps should be able to provide average lamp current values for all popular flasher rhythms. This data permits a simpler calculation for daily load.

NOTE: These surge effects decrease with the number of flashes in multiple flash characters.

5.2. LED LIGHT SOURCES

There are different principles of generating visual light and different levels of complexity of the circuitry used to drive a light emitting diode (LED). Some examples of these drive methods are:

- Passive power supply circuits
- Active power supply circuits
- Switching power supply circuits

Powering LED based light sources may introduce issues requiring attention in the course of proper system integration at AtoN outstations. An example of this is the potential for any LED lantern to be a source of electromagnetic interference (EMI) and may in turn be susceptible to EMI from other equipment.

The power consumption of an array of LEDs or a single LED light source controlled by power input may be calculated similar to that of an incandescent lamp. LEDs however do not have the high starting current reflected in Figure 2 and for practical reasons E_{surge} becomes zero.

5.2.1. COMPLEX LED LIGHT SOURCES

Many contemporary complex LED light sources consist of several subsystems, integrating LED’s, flashers, GPS receivers, measurement and monitoring modules within one product feeding from a single power. In such case, the power consumption budget of a product should be calculated based on manufacturer’s information on all possible power modes expected to occur in the application scenario.

Most often the LED’s are integrated in a lantern that houses an integrated LED power supply and a flasher, usually referred to as a self-contained lantern. The power consumption of such product can be divided into power consumption during flash, power consumption between flashes, and daytime quiescent power consumption.

$$E_{DL} = \left[P_{fl}(W) \times \frac{T_{flash}}{T_{period}} + P_{bfl}(W) \times \left(1 - \frac{T_{flash}}{T_{period}}\right)\right] \times H_{darkness}\left(\frac{h}{day}\right) + P_{idle}(W)\left(24 - H_{darkness}\left(\frac{h}{day}\right)\right)$$

Equation 10 Daily load for a complex LED light source

where:

E_{DL} is the daily load in Wh per day

P_{fl} is the power consumption during flash in Watts.

P_{bfl} is the power consumption between flashes in Watts.

P_{idle} is the daytime power consumption in Watts.

$H_{darkness}$ is the hours of darkness (or hours of operation per day)

To find the energy consumed in a day (daily load) some additional figures are needed:

T_{period} is the light's character period (sec)

T_{flash} is the total duration of flash in a period (sec)

5.3. METAL HALIDE

Metal halide discharge lamps are only ever used within rotating optic and require associated ballast to strike and maintain the ionised arc with the lamp. These ballast units can consume more than their lamp rating, so the ballast must be added when sizing a load. Again, manufacturers should be consulted to determine power requirements at the rated system voltage and temperature; and these values should be confirmed by measuring the devices in a realistic setting.

$$E_{DL} = P_{lb}(W) \times Hours\ of\ Operation\ per\ day(h/day)$$

Equation 11 Daily load for a rotating optic

where:

E_{DL} is the daily load in Wh per day

P_{lb} is the measured / manufacturer figure for lamp and ballast power consumption in Watts.

5.4. FLASHER / CONTROL

The device used to flash or control the light source also requires power. Manufacturers of flashers / controls should be able to provide the power requirements of their units; an average value may be sufficient for high efficiency units. Otherwise, the demand during flash, eclipse and when idle (daytime) may be required to calculate the load profile. In general, the energy demand is calculated as a daily load, as follows:

$$E_{DL(average)} = P_q \times H_{daylight} + P_{bfl} \times (1 - duty\ cycle) \times H_{darkness} + P_{fl} \times duty\ cycle \times H_{darkness}$$

Equation 12 Daily load for a flasher

where:

E_{DL} is the daily load in Wh per day

P_q is the quiescent power consumption in Watts.

$H_{daylight}$ is the hours of daylight in hours per day

P_{bfl} is the power consumption between flashes in Watts

$H_{darkness}$ is the hours of darkness (or hours of operation per day)

P_{fl} is the power consumption during flash in Watts.

5.5. OPTIC ROTATION

Rotating optics have a load associated with the mechanism used to rotate the turntable assembly. Lighthouse services generally leave the turntable rotating continuously, both for operation at night, and during the day to prevent the sun from focusing through the lens panels and damaging the lamps or lamp changer. Therefore, the power requirements for the rotation mechanism and control system should be entered as a continuous load. This load may vary significantly with temperature, so be sure to identify the operating environment when requesting power demand information from the manufacturer.

$$E_{DL} = P_{motor}(W) \times Hours\ of\ Operation\ per\ day(h/day)$$

Equation 13 Daily load for a rotating optic

where:

E_{DL} is the daily load in Wh per day

P_{motor} is the motor and control system power consumption in Watts.

Rotating beacons may use Fixed-ON flashers to regulate voltage and operate the lampchanger; then the energy demand is:

$$E_{DL} = \left[P_{lamp}(W) \times H_{darkness}(h/day)\right] + E_{flasher}(Wh/day) + E_{motor}(Wh/day)$$

Equation 14 Daily load for a rotating optic and light source

5.6. SOUND SIGNAL

Sound signals operate over a wide voltage and temperature range. Request from the manufacturer of the signal the energy demand at the expected operating voltages and the expected operating temperatures.

$$E_{DL} = [P_{blast}(W) \times Duty\ Cycle + P_{silent}(W) \times (1 - Duty\ Cyle)] \times hours\ of operation/day]$$

Equation 15 Daily load for a sound signal

where:

E_{DL} is the daily load in Wh per day

P_{blast} is the *sound signal and driver system* power consumption *during the blast,* in Watts.

P_{silent} is the *sound signal and driver system* power consumption *when silent,* in Watts.

Duty Cycle is the ratio between the on and total character period as a decimal value.

Sound signals under visibility detector control will require historic low visibility hour data to predict their operating time.

5.7. VISIBILITY DETECTOR

Visibility detectors can be used to minimise noise pollution from sound signals. These devices may use heaters in the projector and receiver windows to prevent condensation in cool weather. The temperature when these heaters turn on varies from model to model. You must determine the turn-on temperature of these heaters and have access to temperature data of the area. From this, an idea of how long the heaters will be activated (duty cycle) can be formulated. A data logging recorder is a useful tool to determine the duty cycle of the heaters, however failure to account for an unusually harsh cold spell may cause premature power system failure as the load will be substantially higher. The data logging recorder can also provide useful data as to how many hours the sound signal will be operating.

$$E_{DL} = P_{heater}(W) \times Duty\ Cycle \times 24h/day + P_{projector}(W) \times Duty\ Cycle \times 24h/day$$

Equation 16 Daily load for a visibility detector

where:

E_{DL} is the daily load in Wh per day

P_{heater} is the heater power consumption in Watts.

Duty Cycle is the ratio between the on and total period as a decimal value

$P_{projector}$ is the sensor head and control system power consumption per day

5.8. CONTROL AND MONITORING SYSTEMS

5.8.1. CONTROL EQUIPMENT

Equipment used to control AtoN typically consume power. In general, the power consumption is rated for when the system is operating normally; i.e., main AtoN are operational and using the main power system. The loads associated with these devices are calculated as continuous loads.

$$E_{DL} = P_{active}(W) \times hours\ of operation + P_{standby}(W) \times hours\ of operation$$

Equation 17 Daily load for a monitoring system

where:

E_{DL} is the daily load in Wh per day

P_{active} is the power consumption of all of the active equipment when the AtoN is operational in Watts.

$P_{standby}$ is the power consumption of all of the standby equipment that is not operational per day in Watts

5.8.2. MONITOR SYSTEMS

Monitor systems vary widely in complexity, means of transmission and power demand, with low energy models available for solar powered applications. Transmission methods will greatly affect the power demand. Phone lines, radios and satellite links each have different power requirements. They may use considerable power during data transfer. A strict regime should be established to control the time when the link is in operation. The power demand of the transmission device can usually be ignored if contact is made briefly once or twice a day. In this case, the quiescent demand is calculated as a continuous load and can be used to calculate the daily load. Many monitoring systems allow interrogation from the monitoring centre, and excessive operator-instigated requests for data from a single out-station can cause the energy drain to exceed the design parameters. Consult with the manufacturer of the unit to determine the actual power consumption for the application selected, but it is suggested to measure the current at the site to confirm the design data.

This therefore leads to a quiescent standing load and an increased communication mode when transmitting or receiving date based on a predicted duty cycle.

$$E_{DL} = \left[P_{comms}(W) \times Duty\ Cycle \times 24h/day + (P_{Quiescent}(W) \times (1 - Duty\ Cycle) \times 24h/day)\right]$$

Equation 18 Daily load for a monitoring system

where:

E_{DL} is the daily load in Wh per day

P_{comms} is the power consumption during a typical data exchange in Watts.

Duty Cycle is the ratio between the total communication time and a 24 hour period as a decimal value

$P_{quiescent}$ is the quiescent standing power consumption per day

Monitoring units may offer additional functionality like GPS signal reception and flashing synchronisation, measurement, etc. It is advisable to establish the mission specific power consumption profile of the product with consideration of all relevant factors like ambient temperatures, power supply voltages, and distance from shore stations, etc.

5.9. CHARGE CONTROLLER

Charge controllers are used to manage the energy and charge profiles from a source into a battery system. They provide overcharge protection, load disconnection in the event of low battery voltage and reverse current protection on photovoltaic systems. Charge controllers have both an efficiency and quiescent power requirements. The efficiency figure quoted by manufacturers is variable on power being converted by the regulator from the solar array. A typical figure being 98% efficient at full load. As this energy loss is not constant and varies with charge demand, this load is therefore captured as a factor (battery efficiency) within the IALA solar model, Methods and Ambient Light Levels for the Activation of AtoN Lights

IALA. *Guideline G1039 Designing Solar Power Systems for Aids to Navigation (Solar Sizing Tool)* [2].

This then just leaves the quiescent load for the controller which can be considered a constant and is typically <20mA.

$$E_{DL} = P_{quiescent}(W) \times H_{operation}(h/day)$$

Equation 19 Daily load for a charge controller

where:

E_{DL} is the daily load in Wh per day

$P_{quiescent}$ is the quiescent standing power consumption per day

$H_{operation}$ is the hours of operation per day

5.10. AIS

5.10.1. GENERAL

AIS has the potential to replace or augment existing remote control and monitoring systems, as well as to provide AtoN service in its own right. *IALA. Recommendation R0126 (A-126) The Use of Automatic Identification Systems (AIS) in Marine Aids to Navigation* [4] refers.

The power consumption of an AIS AtoN station depends on which type (1, 2 or 3) of AtoN station is used, and on the setting of a number of parameters which may be configured in the unit. These parameters shown below are optimised to minimise power consumption.

- VDL access method – FATDMA will give substantially lower power drain than RATDMA.
- FATDMA slot selection –Channel A and Channel B slots should be close together in time, to minimise the period for which the processes in the AIS AtoN unit are active. (Assuming the recommended Mode B is used).
- Reporting interval – an extended reporting interval will, of course, reduce power drain, but the interval should satisfy the guidance given in IALA Recommendation *R0126 (A-126)*[1].

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[1] Repeating of the AIS AtoN messages by a local AIS base station, during the reporting interval of the AIS AtoN station, may allow the reporting interval of the AIS AtoN unit to be extended. For example, the AIS AtoN may have a 10 minute reporting interval, but the local AIS base station repeats the AIS AtoN message every frame, i.e. every minute.

- The AIS AtoN unit should be designed or configured to enter into a “sleep” mode when not active.
- Number and types of messages transmitted;
- Transmitter power.

5.10.2. CALCULATION OF THE POWER REQUIREMENTS

The power requirement of an AIS AtoN unit transmitting Type 21 AtoN and Type 6 monitoring messages can be estimated by using the formula below:-

5.10.2.1. RATDMA Operation

$$E_{RX} = [P_s + ((T_s + 60) \times (P_w - P_s))/T_r) \times 24Wh/day]$$

Equation 20 Power requirement for RATDMA operation

where:

E_{RX} is the power consumption when asleep or waiting to transmit

Ps is the power taken by unit when asleep (Watt)

Ts is the time taken for unit to acquire slot map after waking up (secs)

Pw is the power taken by unit when awake, but not transmitting (Watt).

Tr is the reporting interval (secs)

$$E_{T21} = \left[P_t \times (4/2250) \times (\frac{60}{T_r}) \times 24Wh/day\right]$$

$$E_{T6} = \left[P_t \times (2/2250) \times (\frac{60}{T_m}) \times 24Wh/day\right]$$

$$E_{DL} = E_{RX} + E_{T21} + E_{T6} Wh/day$$

Equation 21 Estimate of power consumption for an AIS unit transmitting Type 21 & 6 messages

where:

E_{T21} is the power consumption for Type 21 message transmission

Pt is the power taken by unit when transmitting (Watt)

Tr is the reporting interval (secs)

E_{T6} is the power consumption for Type 6 message transmission

Tm is the reporting interval for monitoring message Type 6 (secs)

E_{DL} is the total daily power consumption

5.10.3. FATDMA OPERATION

Use the same formulae as above, but the parameter T_s will be the time taken for the GPS receiver to obtain a position fix after waking up. (If a DGPS receiver is fitted T_s will be the time taken to obtain a DGPS corrected position fix after waking up.)

Note that P_w will be substantially lower when using FATDMA mode, as there is no requirement for a VHF receivers to be powered up.

5.11. RACON

The power consumption of RACONs is difficult to predict, as the load will be determined by the number of times the RACON is interrogated. Most RACONs have an upper limit on the number of responses broadcast if the unit is continuously interrogated due to a moored ship with the radar left on or an unusually busy channel. Consult with the manufacturer for high, medium and low power demand values for these devices and local pilots in the area to determine what level of traffic exists in the waterway. Alternately energy demand measurements can be made with an integrating ampere-hour or watt-hour meter over a 2 month period during maximum traffic to obtain a meaningful load profile.

$$E_{DL} = \left[P_t(W) \times Duty\ Cycle + P_q(W) \times (1 - Duty\ Cycle)\right] \times 24h/day$$

Equation 22 Daily load for a RACON

where:

E_{DL} is the daily load in Wh per day

P_t is the power taken by unit when transmitting in Watt

P_q is the power taken by unit between periods of transmission in Watt.

Duty cycle is the ratio between the total transmission time and a 24 hour period as a decimal value

6. OTHER LOADS

6.1. NON-ESSENTIAL LOADS

Non-essential loads such as domestic lighting should ideally be under some form of automatic control to ensure that they cannot be left on and drain the power system. Such non-essential load should be sourced from an independent battery system to that of any AtoN and sized to meet the operational demands.

6.2. SEASONAL AIDS

Seasonal aids are operated for a portion of the year and either removed or secured during the period of non-operation.

It is advisable to ascertain that the equipment which is powered off for a significant period of time do not contain internal energy storage. Such energy storage is sometimes used to maintain power to memory devices backing up critical information that might become depleted during non-operation periods. In addition it is important that when powered up by remote control, such equipment does not create excessive power consumption once power is applied.

7. CONCLUSION

Once each load is fully characterised, then the sum of the loads for each day and each night must be calculated to determine the daily energy demand, and hence the system energy balance, battery daily minimum state of charge and seasonal minimum state of charge.

[1] For designing of a solar system, these total loads can be used with the Methods and Ambient Light Levels for the Activation of AtoN Lights

IALA. Guideline G1039 Designing Solar Power Systems for Aids to Navigation (Solar Sizing Tool) [2] to develop an effective solar design.

Using E_{DL}, you can make a conservative system design with a couple of calculations. Calculation of E_{DL} for every day of the year using a design program and comparing it to the battery capacity or energy produced from a renewable energy source will allow you to design a less conservative but cheaper system.

The most critical success factors in the estimation of the energy requirements are:

- The definition of the total load.
- The definition of the load characteristics.

8. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

9. ABBREVIATIONS

Ah	Ampere hour(s)
AIS	Automatic Identification System
AtoN	Marine Aid(s) to Navigation
D	Suns declination angle (in degrees)
DGPS	Differential Global Positioning System
°C	Degrees centigrade
FATDMA	Fixed-Access Time-Division Multiple Access
GPS	Global Position System
h/day	Hours per day
L	Latitude (in degrees)
LED	Light emitting diode
mA	milliampere
mW	milliwatt
n	Number of the day in the Julian calendar
N	North
RACON	Radar beacon
RATDMA	Random Access Time Division Multiple Access
s	second
S	South
V	Volt(s)
VDL	VHF Data Link
W	Watt(s)
Wh/day	Watt hours per day
Ws	Watt seconds

10. REFERENCES

[2] IALA. Guideline G1038 Methods and Ambient Light Levels for the Activation of AtoN Lights

[3] IALA. Guideline G1039 Designing Solar Power Systems for Aids to Navigation (Solar Sizing Tool)

[4] IALA. Recommendation R0126 (A-126) The Use of Automatic Identification Systems (AIS) in Marine Aids to Navigation Services

ANNEX A FURTHER EXPLANATION OF THE HOURS OF DAYLIGHT EQUATION

The derivation begins with the following basic astronomical equation which is stated without proof,

$$cos\theta_h = cosL\ cosD\ cos\omega + sinL\ sinD$$

Equation 23 The angle of incidence

where:

θ_h is the incidence angle of the solar rays upon a horizontal surface = zenith distance = angle between solar rays and vertical line

L is the latitude of site

D is the solar declination

ω is the hour angle

(Note: all angles are in degrees)

From Equation 23

$$\omega = arc\cos\left[\frac{(cos\theta_h - sinL\ sinD)}{(cosL\ cosD)}\right]$$

Equation 24 Hour angle

Sunrise is defined as the time at which the upper limb of the sun becomes visible. At sunrise the centre of the sun is 52 minutes of arc below the horizon as follows: the semi-diameter of the sun subtends an angle of 16 minutes of arc and the effect of atmospheric refraction accounts for an additional 36 minutes of arc. Therefore, sunrise will occur when, in Equation 24, $\theta_h = 90° 52'$. Setting $\theta_h = 90° 52'$ in Equation 24 allows for the calculation of ω_{sunrise}

$$\omega_{sunrise} = arc\cos\left[\frac{(cos90°52' - sinL\ sinD)}{(cosL\ cosD)}\right]$$

$$= arc\cos\left[\frac{(-0.0151 - sinL\ sinD)}{(cosL\ cosD)}\right]$$

Equation 25 Hour angle at sunrise

The amount of time between sunrise and local apparent noon is obtained by converting ω to time (15° of arc in longitude correspond to 1 hour):

$$H_{sunrise-noon} = \omega_{sunrise}/15°$$

where:

$H_{sunrise-noon} is\ in\ hours$

The time from sunrise to sunset is double the time from sunrise to local apparent noon:

$$H_{sunrise-sunset} = 2\omega_{sunrise}/15°$$

Equation 26 Time from sunrise to sunset - degrees

Combining Equation 25 and Equation 26:

$$= \frac{2}{15} arc\cos\frac{(-0.0151 - sinL\ sinD)}{(cosL\ cosD)}$$

Equation 27 Time from sunrise to sunset

ANNEX B WORKED EXAMPLES

B 1. CALCULATION OF THE DAILY LOAD

For a continuous load of 1 Watt, for example, this calculation is expressed as (see Equation 1):

$$E_{DL} = 1W \times 24h = 24Wh/day$$

This means that the energy source need to provide 24 watt-hours every day it operates.

B 2. CALCULATION OF DUTY CYCLE

Therefore, a cyclic daily load of 1 watt that operates 24 hours per day having a character of 3 seconds ON and 3 seconds OFF, is expressed as a daily load of (see Equation 2):

$$E_{DL} = 1W \times 24h/day \times \left[\frac{3\sec ON}{3\sec ON + 3\sec OFF}\right] = 12Wh/day$$

By cycling the load, the daily load in this case is half of a load operating at 100 percent duty cycle. This is an important aspect in conservation of energy.

B 3. CALCULATION OF HOURS OF DARKNESS

To find the maximum daily load for a cyclic load of 1 watt that operates at night, having a character of 3 seconds ON and 3 seconds OFF at 42 degrees N latitude, proceed as follows:

Since the load operates at night, the greatest daily load occurs at the time of the winter solstice when the sun's declination is -23.45°: D=-23.45° perform all calculations in degrees (see Equation 3):

$$H_{daylight} = \left(\frac{2}{15}\right) arc\ cos \left[\frac{-0.0151 - \sin(42) \times \sin(-23.45)}{\cos(42) \times \cos(-23.45)}\right] = 9.1\ h/day$$

giving

$$H_{darkness} = 24 - H_{daylight} = 24 - 9.1 = 14.9\ hours/day$$

Therefore, the maximum daily load (E_{DL}) is:

$$E_{DL} = 1W \times 14.9h/day \times \left[\frac{3\sec ON}{3\sec ON + 3\sec OFF}\right] = 7.45Wh/day$$

$$D = 23.45 \sin\big(1.008(n - 80)\big)\ with\ n = 45\ (Julian\ date\ for\ February\ 14\ is\ 45)$$

To find the daily load for the same cyclic load on February 14 proceed as follows (D = -13.54°):

Perform all calculations in degrees:

$$H_{daylight} = \left(\frac{2}{15}\right) arc\ cos \left[\frac{-0.0151 - \sin(42) \times \sin(-13.54)}{\cos(42) \times \cos(-13.54)}\right] = 10.5\ h/day$$

giving

$$H_{darkness} = 24 - H_{daylight} = 24 - 10.5 = 13.5\ hours/day$$

Therefore, the daily load is:

$$E_{DL} = 1W \times 13.5h/day \times \left[\frac{3\sec ON}{3\sec ON + 3\sec OFF}\right] = 6.75Wh/day$$

B 4. CALCULATION OF THE DAILY LOAD OF A FLASHED INCANDESCENT LAMP

What is the daily load of a 1.15 amp (13.8 watt) lamp that is flashing one second ON, one second OFF, on a day with 13.9 hours of darkness? Using Equation 9

$$E_{DL} = \left[E_{surge} + E_{ss}\right] \times \frac{H}{T_{period}}$$

Calculating E_{surge} from Equation 6, where I = 1.15 amp

$$E_{surge} = 0.1019(1.15)^2 + 1.24(1.15) - 0.3341$$

$$E_{surge} = 1.2Ws$$

Calculating E_{ss} from Equation 6 where P_{ss}=13.8W and T_{flash}=1sec

$$E_{SS} = 13.8 \times 1$$

Calculating E_{DL} from Equation 6 where H=13.9h/day and T_{period} = 2sec

$$E_{DL} = [1.2 + 13.8Ws] \times \frac{13.9h}{2sec}$$

$$E_{DL} = 104Wh/day$$

B 5. CALCULATION OF THE DAILY LOAD OF A FLASHED LED LANTERN

What is the daily load of a 2W LED lantern that is flashing ½ seconds ON, 2½ seconds OFF, on a day with 13.9 hours of darkness? The power consumption between flashes is 150mW and the quiescent power consumption is 10mW. Using Equation 10:

$$E_{DL} = \left[P_{fl} \times \frac{T_{flash}}{T_{period}} + P_{bfl} \times \left(1 - \frac{T_{flash}}{T_{period}}\right)\right] \times H_{darkness} + P_{idle} \times (24 - H_{darkness})$$

Where

P_{fl} = 2W

P_{bfl} = 0.15W

P_{idle} = 0.01W

H = 13.9h

T_{period} = 3s

T_{flash} = 0.5s

$$E_{DL} = \left[2 \times \frac{0.5}{3} + 0.15 \times \left(1 - \frac{0.5}{3}\right)\right] \times 13.9 + 0.01 \times (24 - 13.9)$$

$$E_{DL} = [0.333 + 0.125] \times 13.9 + 0.101 \approx 6.5Wh/day$$

This example demonstrates that the power consumption between flashes can become a significant part of the total daily load in low power LED lanterns.

B 6. CALCULATION OF THE DAILY LOAD OF A LAMP FLASHER / CONTROL

An example showing a simple calculation for a control system using average power data see Equation 12:

$$E_{DL(average)} = P_{average} \times H_{operation}$$

where

$E_{DL(average)}$ is the average daily load in Wh per day

$P_{average}$ is the average control system power in Watts = 240mW continuous from the manufacturers data

$H_{operation}$ is the number of hours of operation per day

$$E_{DL} = 0.240 \times 24 = 5.8Wh/day$$

By combining the energy demand of both the flashed lamp (example B 4) and the controller (see above) to obtain a total system energy demand we get the following:

$$E_{DL\ total} = 104 + 5.8 = 109.8Wh/day$$

B 7. CALCULATION OF THE DAILY OPTIC ROTATION LOAD

As an example, a rotating beacon with a 2.03 Ampere 12 Volt lamp with a fixed rhythm flasher operating at night at 42 degrees N latitude with a 1.2 W continuous motor will have an energy demand of:

Using Equation 13

$$E_{DL} = P_{motor}(W) \times Hours\ of\ Operation\ per\ day(h/day)$$

where:

E_{DL} is the daily load in Wh per day

P_{motor} is the motor and control system power consumption in Watts.

$$E_{DL} = 1.2W^{2} \times 24(h/day) = 28.8Wh/day$$

Rotating beacons may use Fixed-ON flashers to regulate voltage and operate the lampchanger; then the energy demand is:

$$E_{DL} = \left[P_{lamp}(W) \times H_{darkness}(h/day)\right] + E_{flasher}(Wh/day) + E_{motor}(Wh/day)$$

where:

E_{DL} is the daily load in Wh per day

P_{lamp} is the lamp power consumption in Watts.

$H_{darkness}$ is the hours of darkness per day

$E_{flasher}$ is the daily energy for the lamp flasher or control system in Watt hours per day.

E_{motor} is the daily energy for the optic motor and control system in Watt hours per day.

Given the following from above:

P_{lamp} = 24.4 W from above data

$H_{darkness}$ = 14.9 h/day from Calculation of Hours of darkness from example B 3

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[2] *Assuming that the day and night power requirements are the same*

$E_{flasher}$ = 5.8 Wh/day from Calculation of the daily Load of a lamp flasher / control from example B 6

$$E_{DL} = [24.4 \times 14.9] + 5.8 + 28.8 = 398.16 Wh/day$$

B 8. CALCULATION OF THE AUDIBLE SIGNAL LOAD

For example, a sound signal with a power consumption of 21.6 watts during blast, and 0.24 watts when silent with a rhythm of one 3 second blast every 30 seconds, operating for 6 hour per day will have an energy demand of:

Using Equation 15

$$E_{DL} = [P_{blast}(W) \times Duty\ Cycle + P_{silent}(W) \times (1 - Duty\ Cyle)] \times hours\ of operation/day]$$

where:

E_{DL} is the daily load in Wh per day

P_{blast} is the sound signal and driver system power consumption during the blast, in Watts.

P_{silent} is the sound signal and driver system power consumption when silent, in Watts.

Duty Cycle is the ratio between the on and total character period as a decimal value

$$Duty\ Cycle = \frac{3s\ ON}{3s\ ON + 27s\ OFF} = 0.10\ or\ 10\%$$

$$E_{DL} = [21.6(W) \times 0.1 + (0.24(W) \times 0.9)] \times 6$$

$$E_{DL} = 14.256 Wh/day$$

B 9. CALCULATION OF A VISIBILITY DETECTOR LOAD

As an example, a visibility detector has a power demand of 6 watts with a heater load of 24 watts. The heaters turn on when the ambient temperature is below 10°C. Temperature data for the area indicates that the average minimum temperature is below 10°C between November and March and it is estimated that they will be activated 50% of the time during this period. The energy demands are:

Using Equation 16

$$E_{DL} = \left[P_{heater}(W) \times Duty\ Cycle \times 24h/day + (P_{projector}(W) \times Duty\ Cycle \times 24h/day)\right]$$

Equation 28 Daily load for a visibility detector

where:

E_{DL} is the daily load in Wh per day

P_{heater} is the heater power consumption in Watts.

Duty Cycle is the ratio between the on and total period as a decimal value

$P_{projector}$ is the sensor head and control system power consumption per day

$$E_{DL\ Nov-Mar} = [24W \times 0.50 \times 24h/day + (6W \times 1.0 \times 24h/day)] = 432 Wh/day$$

$$E_{DL\ Apr-Oct} = [6W \times 24h/day] = 144 Wh/day$$

B 10. CONTROL AND MONITORING SYSTEMS

For example:

A typical 12V telemetry systems has a quiescent current of 110mA and monitors all of the input continuously. On change of state the unit will power up the modem and communicate to the monitoring centre. The communications typically last 3 minutes and the equipment current increases to 305mA during this period. Typically the unit communicates 12 time a day.

From Equation 18

$$E_{DL} = \left[P_{comms}(W) \times Duty\ Cycle \times 24h/day + (P_{Quiescent}(W) \times (1 - Duty\ Cycle) \times 24h/day)\right]$$

Equation 29 Daily load for a monitoring system

where:

E_{DL} is the daily load in Wh per day

P_{comms} is the power consumption during a typical data exchange in Watts.

Duty Cycle is the ratio between the total communication time and a 24 hour period as a decimal value

$P_{quiescent}$ is the quiescent standing power consumption per day

$$E_{DL} = \left[P_{comms}(W) \times Duty\ Cycle \times 24h/day + (P_{Quiescent}(W) \times (1 - Duty\ Cycle) \times 24h/day)\right]$$

$$E_{DL} = [3.66(W) \times 0.025 \times 24h/day + (1.32(W) \times (1 - 0.025) \times 24h/day)]$$

$$E_{DL} = 2.196 + 30.88 = 33.084Wh/day$$

B 11. CALCULATION OF A CHARGE CONTROLLER LOAD

As an example, a small charge controller on a solar system has a peak efficiency at full load of 96% and a quiescent current of 10mA on a 24V system. The energy demand for this system is as follows:

Using Equation 19

$$E_{DL} = P_{quiescent}(W) \times H_{operation}(h/day)$$

Equation 30 Daily load for a charge controller

where:

E_{DL} is the daily load in Wh per day

$P_{quiescent}$ is the quiescent standing power consumption per day

$H_{operation}$ is the hours of operation per day

$$E_{DL} = 0.24(W) \times 24(h/day) = 0.576Wh/day$$

B 12. CALCULATION OF AN AIS UNIT USING RATDMA ACCESS METHOD

As an example an AIS unit fitted to a buoy has a sleep power demand of 12mW, a wakes ups every 3 minutes during which the power demand is 0.6W. The unit then takes 4 seconds to determine which slots to transmit in. The unit transmits on channel A and B during which the power for transmission is 30W

Using 0

$$E_{RX} = [P_s + ((T_s + 60) \times (P_w - P_s))/T_r) \times 24Wh/day]$$

Equation 31 Power requirement for RATDMA operation

where:

Ps is the power taken by unit when asleep (Watt)

Ts is the time taken for unit to acquire slot map after waking up (secs)

Pw is the power taken by unit when awake, but not transmitting (Watt).

Tr is the reporting interval (secs)

$$E_{RX} = [P_s + ((T_s + 60) \times (P_w - P_s))/T_r) \times 24Wh/day]$$

$$E_{RX} = [0.012 + ((4 + 60) \times (0.6 - 0.012))/180) \times 24Wh/day]$$

$$E_{RX} = 5Wh/day$$

For message 21 the energy demand is:

$$E_{T21} = \left[P_t \times (4/2250) \times (\frac{60}{T_r}) \times 24Wh/day\right]$$

$$E_{T21} = \left[30 \times (4/2250) \times (\frac{60}{180}) \times 24Wh/day\right]$$

$$E_{T21} = 0.43Wh/day$$

For message 6 the energy demand is:

$$E_{T6} = \left[P_t \times (2/2250) \times (\frac{60}{T_m}) \times 24Wh/day\right]$$

$$E_{T6} = \left[30 \times (2/2250) \times (\frac{60}{180}) \times 24Wh/day\right]$$

$$E_{T6} = 0.213Wh/day$$

For the total daily load:

$$E_{DL} = E_{RX} + E_{T21} + E_{T6} Wh/day$$

$$E_{DL} = 5 + 0.43 + 0.213Wh/day$$

$$E_{DL} = 5.643Wh/day$$

$$E_{DL} = E_{RX} + E_{T21} + E_{T6} Wh/day$$

Equation 32 Estimate of power consumption for an AIS unit transmitting Type 21 & 6 messages

where:

E_{DL} is the total daily power consumption

E_{RX} is the power consumption when asleep or waiting to transmit

E_{T21} is the power consumption for Type 21 message transmission

E_{T6} is the power consumption for Type 6 message transmission

$$E_{DL} = E_{RX} + E_{T21} + E_{T6} Wh/day$$

$$E_{DL} = 5 + 0.43 + 0.213Wh/day$$

$$E_{DL} = 5.643Wh/day$$

B 13. CALCULATION OF A RACON LOAD

The calculation below is a typical example based on a single manufacture, due consideration must be given to the equipment manufacturers data in calculating the load.

For example, a RACON has a quiescent current of 24 mW when idle and 8.4 W when transmitting. The duty cycle is limited to 50%. Therefore, as a worst case scenario, if the RACON is continuously interrogated:

Using Equation 22

$$E_{DL} = \left[P_t(W) \times Duty\ Cycle + P_q(W) \times (1 - Duty\ Cycle)\right] \times 24h/day$$

Equation 33 Daily load for a RACON

where:

E_{DL} is the daily load in Wh per day

P_t is the power taken by unit when transmitting Watt

P_q is the power taken by unit when between periods of transmission in Watt.

Duty cycle is the ratio between the total transmission time and a 24 hour period as a decimal value

$$E_{DL} = \left[P_t(W) \times Duty\ Cycle + P_q(W) \times (1 - Duty\ Cycle)\right] \times 24h/day$$

$$E_{DL} = [8.4(W) \times 0.5 + 0.024(W) \times (1 - 0.5)] \times 24h/day$$

$$E_{DL} = 101.1Wh/day$$

B 14. CALCULATION OF A SEASONAL ATON

To calculate the energy demand, a seasonal buoy operating at 42 degrees N with a 1.15 amp lamp with a FL6(0.6) rhythm operating at night and deployed between 1 April and 31 October will have the following energy demand:

From section 4.2, calculate the suns declination (D) for the calendar limits

$$D_{1\ Apr} = 23.45\sin\,(0.965(91 - 80)) = 4.320°$$

$$D_{31\ Oct} = 23.45\sin\,(0.95(308 - 266)) = 14.125°$$

Using Equation 3 and inserting the values of D from above and L for latitude to calculate the hours of daylight, and hence darkness.

$$H_{daylight\ 1\ Apr} = \frac{2}{15} arc\ cos\left[\frac{-0.015 - sin42° \times sin4.32°}{cos42° \times cos4.32°}\right] = 12.7h/day$$

$$H_{darkness\ 1\ Apr} = 24h/day - 12.7h/day = 11.3h/day$$

$$H_{daylight\ 31\ Oct} = \frac{2}{15} arc\ cos\left[\frac{-0.015 - sin42° \times sin - 14.125°}{cos42° \times cos - 14.125°}\right] = 10.4h/day$$

$$H_{darkness\ 31\ Oct} = 24h/day - 10.4h/day = 13.6h/day$$

Therefore, the night time load will be the greatest on October 31.

Then calculating the average energy demand using Equation 9:

$$E_{lamp} = \left(E_{surge} + P_{ss} \times T_{flash}\right) \times \frac{H}{T_{period}}$$

$$E_{lamp} = \left[(1.2Ws + (13.8W) \times (1sec) \times \frac{13.6h/day}{6sec}\right] = 34.0Wh/day$$

where:

E_{surge} = 1.2Ws

P_{ss} = 13.8W

T_{flash} = 1sec

H = 13.6h/day

T_{period} = 6sec

Now determining the total maximum daily load using the flasher power demand from example B 6 is:

$$E_{DL} = 34.0Wh/day + 5.8Wh/day(flasher\ dissipation) = 39.8Wh/day$$