PSA Inverter Programming Example

(From Hybrid Energy Systems Learning Guide, Learning Outcome 8) [1]

Programming of Interactive inverter

Filling in the details of the inverter control strategy requires a sound knowledge of the operation of the power system in question and of the programming parameters for the inverter being used. Each make of inverter is different, and changes are made from time to time as the product evolves. The manufacturer's documentation is *essential reading*, not something to look when all else fails!

The inverter programming parameters can be as important to the correct operation of the system as the actual sizing of the components. Incorrect programming is a common cause of problems with system performance. While most inverters will be supplied with a set of default parameter values that will typically work in some reasonable fashion, it is important not to take this for granted. In any case, component sizes must always be entered.

The following example illustrates programming of a PSA inverter, from given system parameters. While the programming for other inverters will be different, this example will give you a feel for the level of detail and the kind of thinking involved in programming this type of inverter.

Example 1 PSA Interactive Inverter Programming

The system in question consists of:

- 24 V 3 kVA PSA Inverter
- 8 kVA Generator
- 24 V Bank of 1600 Ah (C100) flooded lead acid batteries
- a 1.5 kW Solar Array operating under average irradiation of 5 kWh per day.

The system requires the generator to start daily. The total daily load is 20 kWh, and it is expected that the generator will operate for approximately 3 to 4 hrs providing approximately 40% of the load direct and 60% (12kWh) will then be supplied by the battery/inverter system. The load profile is such that the typical load, when generator is NOT operating is about 1000 watts for about 6 hours and 400 watts for about 14 hours. The large loads tend to operate at night.

The battery manufacturer has supplied the following specifications:

- Boost Voltage 2.5 V per cell
- Float Voltage 2.4 V per cell
- Battery must never be taken below 1.85 V per cell

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[1] This worked example originated with work done by Geoff Stapleton of Global Sustainable Energy Solutions for SEIA (now BCSE – Australian Business Council for Sustainable Energy), for their Hybrid Power Systems endorsement course. The solution was developed and documented by Paul Monsour of the Renewable Energy Centre at Brisbane North Institute of TAFE. The Hybrid Energy Systems Learning Guide, of which this document is an extract, is one of an award winning series of Learning Materials written to meet the off-job training requirements of the nationally accredited Renewable Energy Units of Competence and Qualifications. See http://www.bnp.tafe.net/ren_energy/

- Maximum Charge current 10% of C_{10} rate.
- C_{100} capacity is 1600 Ah, C_{50} is 1280 Ah, C_{25} is 1140 Ah, C_{10} is 960 Ah.
- It is fully charged when charge current reaches 40 amps
- Batteries should be equalised every 14 days

The inverter manufacturer has stated that the inverter can supply a maximum current equal to its full rating. There is a 50mV/100A shunt installed to record the renewable current.

The customer would prefer the generator did not run between 11pm and 7am.

Determine the value for each programming parameter for the inverter, for the above system.

Solution

Each of the parameters must be determined from the system component specs and the desired operating regime. A process for determining each of the above parameters is described below. The parameters are listed in a slightly different order than that usually presented in the manufacturer's literature, in order to simplify the explanation. Please note that a detailed description of each of these parameters is contained on the CD-ROM accompanying this Learning Guide.

Component sizes

Parameter name	*Description*
BatSize Ah	***Battery size***

The battery size to be entered here is the capacity *at the average discharge rate*. This means that some knowledge of the load is required, and ideally, the load profile. From the above information, we have 6 h of 1 kW demand, and 14 h of 400 W demand. This accounts for $6 \times 1 + 14 \times 0.4 = 11.6$ kWh. The remaining 4 hours in the day when the genset runs, must make up the 20 kWh total, i.e. 8.4 kWh. Assuming an average load over the 4 hours, this amounts to a load of 2.1 kW. Given that the large loads operate at night, we can assume that the "genset on" period starts at 6 pm. Based on the above, simplified info, the load profile is as shown below.

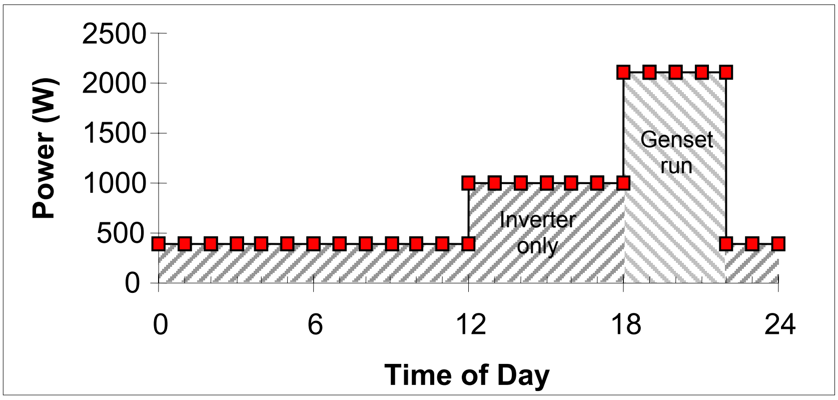

Figure 1 Load profile for Example 1.

For each of these load levels, we can determine the discharge rate of the battery, and then estimate an average figure.

$$I_{batt} = \frac{P_{dc}}{V_{dc}} = \frac{\frac{P_{ac}}{\eta_{inv}}}{V_{dc}}$$

For the purpose of this exercise, we can assume a typical inverter efficiency of 0.85. Therefore:

$$For\ P_{a.c.} = 400\ W; \frac{\frac{400}{0.85}}{24} = 19.6\ A$$

$$For\ P_{a.c.} = 1000\ W; \frac{\frac{1000}{0.85}}{24} = 49.0\ A$$

$$For\ P_{a.c.} = 2100\ W; \frac{\frac{2100}{0.85}}{24} = 103\ A$$

The determination of the discharge rate is iterative – we have just calculated I_X, and we know that $C_X = I_X \times X$, i.e. $X = \frac{C_X}{I_X}$ but the value of C_X that we should use to find X, itself depends on X! We can do a guesstimate by inspecting the discharge rates associated with each of these capacities:

For C_{100} = 1600 Ah; I_{100} = 16 A
For C_{50} = 1280 Ah; I_{50} = 25.6 A
For C_{25} = 1140 Ah; I_{25} = 45.6 A
For C_{10} = 960 Ah; I_{10} = 96 A

Now, looking at the load profile, we need to find an average for the discharge rate, weighted according to the amount of energy taken out at each rate. Since there are a number of approximations in this process, we need not worry about calculating it – by inspection we can say that the average discharge rate will be around the 25 h rate.

We will therefore use C_{25} = 1140 as the value for this parameter!

GenMax kW	*Genset rating*

Easy! The biggest trick here is knowing that the parameter is in kW.
Given S_{gen} = 8 kVA (assume 0.8 pf), then:

$$P_{gen} = 8 \times 0.8 = 6.4\ kW$$

Genset start conditions

The PSA inverter has a number of conditions on which the genset may start. Several of these are based on amp-hour counting and time of day. These are illustrated in Figure 2 (a) and (b), along with parameters related to inverter shutdown. Also illustrated are two similar parameters based on battery voltage.

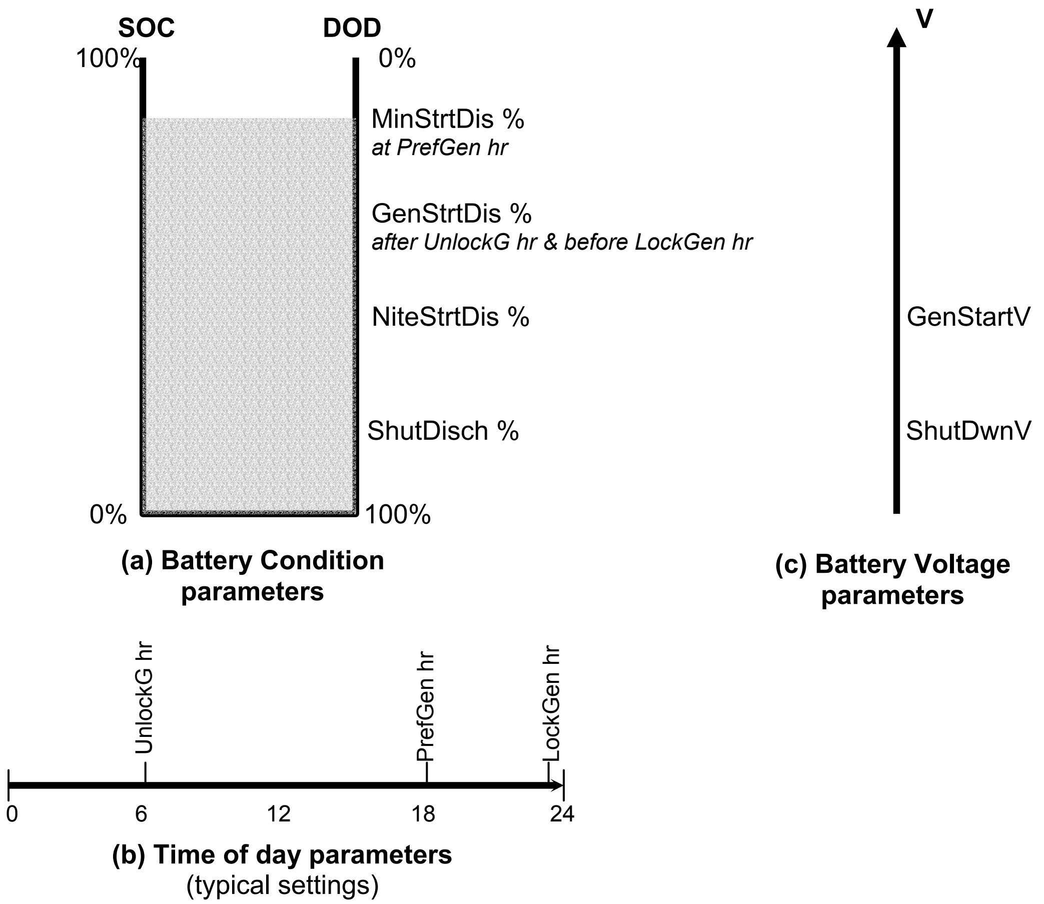

Figure 2 Relationships between battery parameters

MinStrtDis %	***Min DOD for start at preferred hour***
PrefGen hr	***Preferred time for genset starts on minimum DOD***

This parameter is especially important if the genset is likely to be run every day or two. Correct timing can minimise the genset run-time and maximise battery life. For example, poor timing of the genset run can cause the battery to be full at the beginning of the day, thereby potentially wasting solar input and requiring more genset running. If the daily period of highest load is met from the battery instead of the genset, the battery will discharge further, resulting in longer genset run time to re-charge.

For a typical household load, demand is at its maximum just after dark, and the high load period extends for several hours. This is usually considered to be the best time to run the genset because it will be well loaded, PV power is not available, and occupants are still awake. Genset, inverter and battery sizing should allow battery recharge within 4 – 6 hours, thereby leaving a period of night time discharge, providing capacity for the PV array to replace during the day. In this example, the large loads are specified as operating at night, so **6 pm (1800, or 18) would be a reasonable time for this parameter (PrefGen hr)**.

In order for the PrefGen hr to be relevant, the battery must have discharged to the MinStrtDis % level. Therefore, for daily genset running, MinStrtDis % must be set to a value of discharge that would be reached by that time on a day with “typical conditions”.

Assuming that the load is reasonably constant from day to day, we have two cases to consider: a "good " solar day and a poor solar day. Given that about 60% of the daily load (12 kWh) is provided by the battery, we know that this must be recharged by the genset, and renewables. Considering first a "no solar day":

$$Battery\ DOD\ \% = \frac{discharge}{capacity}$$

Now "*discharge*" can be determined from the a.c. load, divided by inverter efficiency, i.e.:

$$discharge = \frac{12\ kWh}{0.85} = 14.1\ kWh$$

In amphours;

$$discharge = \frac{14100\ Wh}{24\ V} = 588.2\ Ah$$

Then

$$Battery\ DOD\ \% = \frac{588}{1140} = 51.6\%$$

By contrast, on a good solar day (take average irradiation), the PV input would be:

$$E_{array} = P_{STC} \times PSH \times f_{derate}$$

Taking a conservative derating typical for inland Australia, f_{derate} = 0.8, then:

$$E_{array} = 1.5\ kW \times 5 \times 0.8$$
$$= 6\ kWh$$

Then

$$discharge = 14.1 - 6\ kWh = 8.1\ kWh$$

$$discharge = \frac{8100\ Wh}{24\ V} = 337.5\ Ah$$

$$Battery\ DOD\ \% = \frac{338}{1140} = 29.6\%$$

Thus, on a day with average load, the DOD will range from about 30% to about 50%. To ensure that the genset starts, the value of MinStrtDis % must be set to *less than* 30 %. In fact since better than average solar days can occur, and since the daily load can vary, we can make this comfortably below 30 %, say 20 - 25%. If it was set to zero, the genset would always start at PrefGen hr, even when the occupants went on holidays, or the load was very low for other reasons. **For this example, lets choose 20% for MinStrtDis %.**

GenStrtDis %	***Standard DOD that starts genset if not locked out***
LockGen hr	***Lockout time after which genset starts only on max DOD (or low voltage)***
UnlockG hr	***Time after which generator starting conditions are restored***

A genset lockout time can be programmed LockGen hr and UnLockG hr. This is typically chosen to correspond with sleep time. Note however that this only prevents the genset from *starting* during this time. If already running, it will continue until the necessary conditions are met. In this example, the client has specified a lockout time of 11 pm (2300) to 7 am (0700). **Therefore, LockGen hr = 23 and UnlockG hr = 7.**

GenStrtDis provides the next set point for the genset to start, provided it is not locked out. This is relevant if the MinStrtDis% was not reached at PrefGen hr, but at some later stage, continued discharge required that the genset be started. This condition may also occur if an unusually high demand occurs during the day, causing the genset to start before PrefGen hr.

The value of GenStrtDis should be such that it does not cause a genset start to occur before PrefGen hr, during "normal" conditions, although this may occur during particularly overcast conditions or as a result of high energy consumption. Considering a "no sun" day, the DOD is 50% by PrefGen hr.

In this example, we will choose GenStrtDis to be 40%.

NiteStrtDis %	*Emergency DOD that starts genset regardless of time*

This parameter will cause the genset to start regardless of time of day (i.e. it is not limited by the lockout time). It can therefore be considered as an "emergency" start condition. This can be set to a value between the design daily DOD, up to the design maximum DOD. In this example, these values are not given, however we also know that this parameter must be a deeper discharge than GenStrtDis. Considering the design rule of typical maximum daily DOD of 50%, **we will choose NiteStrtDis% = 50%.**

GenStartV	*15s average battery voltage which will start genset*

This voltage provides a "safety net" if for some reason the discharge amphour count becomes too erroneous and the genset does not start. It is not constrained by time of day, so again can be considered an "emergency" condition. It is also conceivable that very high loads could cause this condition to occur, however, the inverter should already have initiated a genset start if it is overloaded (this is preset and related to the inverter's power ratings, not user programmable).

Typically this value would be set at a little below the nominal cell voltage of 2 V, and safely above the "end of discharge" voltage (typically 1.8 to 1.9 V, here 1.85 V_{pc}). **In this case we will chose 1.95 V per cell, which for this example translates to 23.4 V.**

Genset Stop Conditions

There are several conditions which will initiate a genset stop signal. Once the genset is started for whatever reason, it will continue to run provided there is enough a.c. load and that the batteries are fully charged.

The fully charged condition is determined by the battery charging power having reduced to a certain level. This parameter (MinChrgPwr) is actually the current in Amps, calculated as a percentage of the battery capacity (Ah), below which the genset will stop.

The load on the genset is also monitored, and the genset will stop if it becomes too lightly loaded, below GenHoldOn %. This is simply a percentage of the genset power rating parameter GenPwr.

See Figure 3 for a graphical representation of where these parameters are measured in the system.

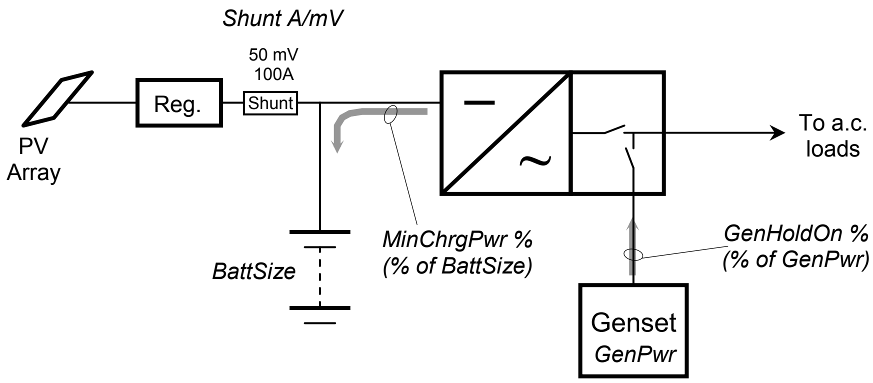

Figure 3 Power system block diagram showing relationship of certain parameters to physical quantities

GenHoldOn %	***2 min average genset output that holds genset on***

This parameter must be set high enough to ensure that the genset does not run for loads which the inverter alone could handle, and low enough to ensure that the genset will not undergo frequent start/stop cycles to deal with large loads being used. Since we have not been given any information about the detail of the loads powered by this system, this will be something of a guess for this example. We will choose a figure between the minimum of 32% (= 0.32 × 6.4 = 1.96 kW) and maximum of 50% (= 0.5 × 6.4 = 3.2 kW) allowable for this parameter (see Table 1).

For this example we will choose GenHoldOn% = 40%.

MinChrgPwr %	***Charging current above which genset keeps running***

We must be careful about this parameter, as it can have potentially disastrous effects on the genset. As the battery charges, its current reduces to essentially a float level. This is illustrated in Figure 4. If the value of MinChrgPwr is set too low, the charge current will never reach this value, and the genset will run indefinitely (i.e. until it runs out of fuel or something else stops it!)

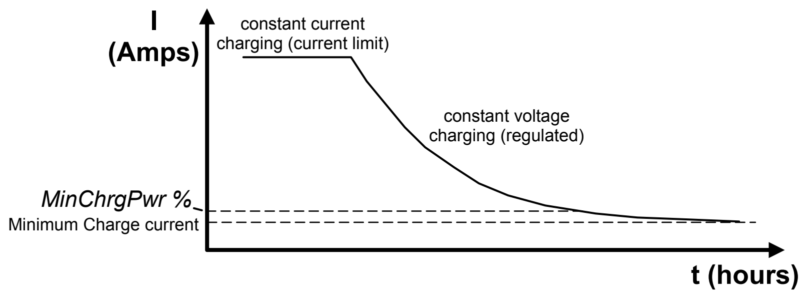

Figure 4 Charge characteristic of lead acid battery with current limited constant voltage charger (e.g. interactive inverter in charging mode)

This parameter is typically set at near 4%. In this example, we are told that the battery is fully charged when the charging current reduces to 40 A. We can therefore calculate the percentage as:

$$\textit{Minimum charge current} = \frac{40}{1140} = 3.5\%$$

MinChrgPwr needs to be set slightly higher than this, e.g. 4%. This corresponds to a minimum charge current of 0.04 × 1140 = 45.6 A. Note that the battery need not be fully recharged (i.e. to 100%) every day. Terminating the charge cycle at less than 100% SOC will reduce the period of light loading on the genset which occurs towards the end of the charge cycle, and the battery will be boost charged periodically (e.g. every 14 days) to equalise the batteries and prevent permanent sulphation.
Therefore, we can leave MinChrgPwr at the default of 4.0%.

Miscellaneous A.C. control parameters

NomAc Volt	***Nominal AC output voltage***

These days, **this is simply 230 V** in Australia, for a single phase supply (note that many existing inverters will have been set to 240 V).

RevPwr kW	***Reverse power shut off to prevent genset motoring***

The value of this parameter is not critical, but it must not be made too large. Normally, reverse power flow into the genset will only occur for a brief moment if the genset is manually stopped or runs out of fuel, or there is a fault. **The default value is usually acceptable (e.g. –0.5 kW)**.

Hi Lim Hz	***Maximum frequency allowed for synchronisation***
Lo Lim Hz	***Minimum frequency allowed for synchronisation***

The inverter can cope with a wide range of genset frequencies, however, these parameters should not be set too far apart, as damage to loads could result. Frequencies of ± 10% of nominal should be considered the limit. If the genset does not operate within these limits, there is a problem with the governing and it should be fixed. This is sometimes a problem with old gensets (e.g. where the client wants to use an existing old genset with a new hybrid power system).

At the other extreme, too narrow a frequency window will mean that the inverter may never be able to synchronise if the genset is not tightly governed.

The default values of 55 Hz for Hi Lim Hz and 45 Hz for Lo Lim Hz are acceptable.

Inverter emergency shutdown conditions

ShutDisch %	***Battery DOD which triggers inverter shutdown***
ShutDwnV	***15s avg battery voltage which triggers inverter shutdown***

As indicated in Figure 2, these parameters must be set below those used to start the genset, and should only ever operate in an abnormal condition. It is used to protect the battery from over-discharge, when the genset has failed to start, or in the extremely unlikely even of a prolonged very high load which discharges the battery even when the genset is running.

ShutDisch % should be set to something below the design maximum depth of discharge. While this is not specified in this example, we know it must also be below the parameter NiteStrtDis %. We could choose as much as 70% at most. **For this example, we will choose 65%.**

In this example we have been given that the battery must not fall below 1.85 V_{pc}. ShutDwn V should therefore be at or above this value. **In this example, we will use 1.85 V_{pc} = 22.2 V.**

Battery charging parameters

The parameters relating to battery charging cover both charging from the renewable source, which the inverter can monitor (but not control), and its own battery charging function which is of course fully controlled.

RenFloat V	*Renewable voltage required for RenFloatHr to delay boost*
RenFloat hr	*Time required at RenFloatV to delay boost charging ½ day*

These parameters should be set such that the battery can be considered fully charged when these conditions are met. Refer to Figure 5 for an illustration of the relationship of these parameters to a charging cycle on an ideal day, assuming a standard "Boost/Float" PV regulator is used. Note that RenFloat hr must be set at *less than* the time measured on the diagram, to ensure that this condition will be reached.

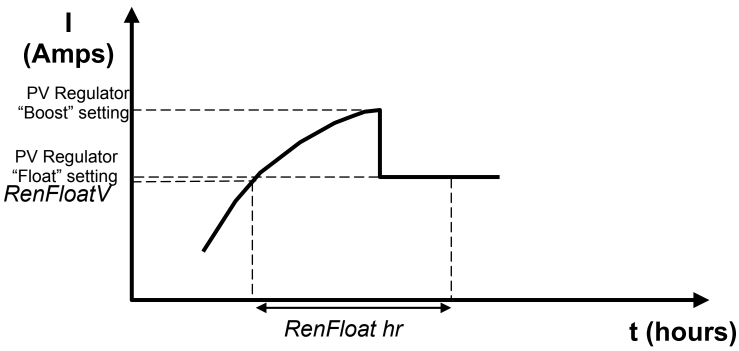

Figure 5 One interpretation of the relationship between renewable charging parameters and PV charging cycle (simplified).

Given that the float voltage is specified at 2.4 V_{pc}, then we could set RenFloatV at about this level. **RenFloatV = 2.4 × 12 = 28.8 V.**

RenFloat hr can be left at the default value of 2 h.

Shunt A/mV	*Current measuring shunt calibration*

This is given as 100A/50mV. **This translates to 2 A/mV for this parameter.**

The inverter's battery charging process is illustrated in Figure 6.

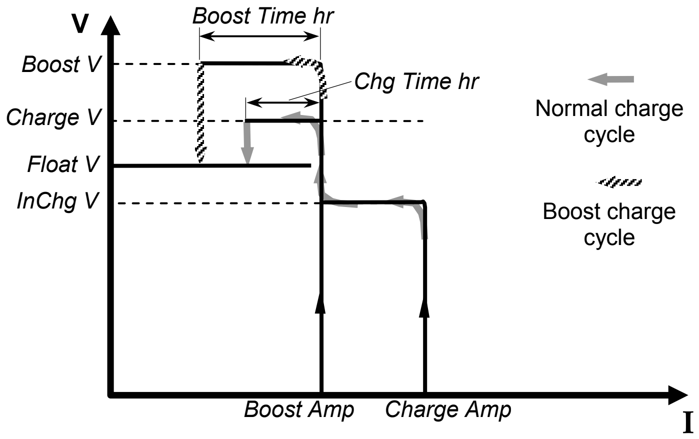

Figure 6 Battery charging process and parameters

In Chrg V	*Initial charge voltage*

This voltage must be comfortably lower than the float voltage – it is the limit voltage to which the maximum charge current of the inverter/charger will be applied, e.g. 2.2 to 2.3 V. **In this example we will choose 2.25 V_{pc} = 27.0 V.**

Charge V	*Charge voltage until timeout and < minimum charge rate*

This voltage is typically equal to a "high float" setting, e.g. 2.4 V_{pc} (this is the default). This must be set in conjunction with Float V, which will be lower.
In this example, we will use the float voltage specified for the battery under solar duty, Charge V = 2.4 V_{pc} = 28.8 V.

Float V	*Float voltage applied after battery is charged*

This can be lower than Charge V, as it is only used when the batteries have been already charged, and the genset is still running. A lower value will also reduce load on the genset, allowing it to stop sooner.
In this example, we will use a float voltage less than Charge V, and where gassing will be very minimal: Float V = 2.3 V_{pc} = 27.6 V.

Chg Time hr	*Minimum time for which charge voltage is held*

The default for this parameter is 0.3 h or 18 minutes.
In this example, we will use the default value specified as 0.3 h.

Boost V	*Maximum battery voltage during boost or equalise*

In this example, the boost voltage is given as 2.5 V_{pc}, i.e. **Boost V = 2.5 V_{pc} = 30.0 V.**

Bst Time hr	*Boost time*

The default value is 3 h. The battery manufacturer's data should be consulted if possible. Given that this will occur every 14 days (see BstFreq Day), 2 – 3 h would be typical. **In this case we will choose 2 h (just for the hell of it).**

Charge Amp	*Maximum battery charging current*

The data we are given says that the battery should not be charged at more than the 10 h rate (i.e. 10% of C_{10}). **So, from above, Charge Amp = 96 A.**

Boost Amp	***Maximum battery boost or equalise current***

To avoid overheating or other damage to the batteries, the boost current should be kept at or below the 20 h rate (I_{20}). In this case we are given C_{25} = 45.6 A, which will be close enough, **so we will choose Boost Amp = 45 A**

BstFrq Day	***Number of days between automatic boost cycles***

In the data given, this is recommended as 14 days.

Time hr	***Setting of the time in hours***
Time min	***Setting of the time in minutes***

The final two parameters to be entered into the inverter are the current time and date.

In summary, the inverter parameters are as follows:

Parameter, >min and <max	**Description**	**Default value**	**Req'd value**
BatSize Ah >20, < 3000	Battery size	200	1140
GenMax kW >1.0, < 7.5	Genset rating	3.0	6.4
MinStrtDis % > 4, <80	Min DOD for start at preferred hour	5	20
GenStrtDis % > 4, <80	Standard DOD that starts genset if not locked out	20	40
NiteStrtDis % > 4, <80	Emergency DOD that starts genset regardless of time	30	50
GenStartV > 20.5, <26.2	15s average battery voltage which will start genset	23.4	23.4
GenHoldOn % >20, <50	2 min average genset output that holds genset on	32	40
MinChrgPwr % > 2, < 9	Charging power above which genset keeps running	4	4
NomAc Volt >210, < 260	Nominal AC output voltage	230	230
RevPwr kW >-3.00, <-0.10	Reverse power shut off to prevent genset motoring	-0.50	-0.5
Hi Lim Hz < 65.00,>50.10	Maximum frequency allowed for synchronisation	55.0	55.0
Lo Lim Hz < 49.90,>43.00	Minimum frequency allowed for synchronisation	45.00	45.0
ShutDisch % > 0, <90	Battery DOD which triggers inverter shutdown	60	65
ShutDwnV > 20.4 , < 22.2	15s avg battery voltage which triggers inverter shutdown	22.2	22.2
RenFloat V > 24.5, <28.8	Renewable voltage required for RenFloatHr to delay boost	27.24	28.8
RenFloat hr >0.3, < 12.0	Time required at RenFloatV to delay boost charging ½ day	2.0	2.0
Shunt A/mV > 0.20, < 5.00	Current measuring shunt calibration	1.00	2.00
In Chrg V >25.2 , < 28.8	Initial charge voltage	27.96	27.00
Float V >25 ,<30	Float voltage applied after battery is charged	27.96	27.6
Charge V >25, < 30	Charge voltage until timeout and < minimum charge rate	28.8	28.8
Chg Time hr >0.3, < 12.0	Minimum time for which charge voltage is held	0.3	0.3
Boost V >26, < 31.5	Maximum battery voltage during boost or equalise	26.0	30.0
Bst Time hr >1.0, < 12.0	Boost time	3.0	2.0
Charge Amp >10, < 125	Maximum battery charging current	100	96
Boost Amp >5, <100	Maximum battery boost or equalise current	90	45
BstFrq Day >3, <63	Number of days between automatic boost cycles	14	14
PrefGen hr>5, <30	Preferred time for genset starts on minmum DOD	20	18
LockGen hr >5, <30	Time after which genset starts only on low bat or max DOD	20	23
UnlockG hr >5, <30	Time after which generator starting conditions are restored	20	7
Time hr >0, <23	Setting of the time in hours	20	-
Time min >0, <59	Setting of the time in minutes	20	-

Table 1 PSA Genset-Interactive Inverter programming parameters

End of PSA Interactive Inverter Programming Example

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