



PALADIN - A guardian of Solar Values

(Software versions 624 and up - please read addendum)

Display Decode

The display for PALADIN is not at all important for its' correct operation, but there is a host of information there which can be useful. There are no buttons, touch pads / screens or areas to play with at all. Once installed it just works. The results are in the meter numbers or your monthly / quarterly bill.

To avoid tl::dr (too long :: didn't read), here is a brief summary of the display. The deeper explanation can be found below in the FAQs.

The overarching rules for this display are:

1. When there is nothing interesting to show, the associated line will be blank.
2. When there is no activity on that line, the line will show totals for the day so far if any.
3. There is no rounding or smoothing of data. Even the 'noise' is interesting (see FAQ).

The 4 line display can be best described line by line:

Line 1

To the left is the hot water tank temperature in degrees Celsius.

Center is either terse words to indicate what is happening now apart from when Paladin is transferring excess solar, when this displays a 'throttle' graphic' to give sense of how hard Paladin is working.

On the right is the number of hours | minutes that excess PV transfer has taken place so far today.

Line 2

Is the Grid activity? This line is always displayed and shows either IN or OUT and a number in Watts. If there is excess PV this will bounce between IN and OUT. Remember these are snapshots of what is happening 3200 times a second internally and the gross values of the numbers while bouncing are not actually what is passing through the meter. When there is no excess PV, it will always show IN. If your hot water is at maximum or you have PV in excess of your heater element, it will show OUT.

Line 3

Is the Transfer PV to Hot water data? While there is active PV diversion the line shows 'DIVERT' and a 'TOT' with a value for each in Watts. When diversion stops the line changes to 'X'FERED' and 'TOP', which shows the total transferred and topped up (from the grid) respectively.

Line 4

Is the PV data line? If you have that CT fitted. This is absolutely just 'info only' and has no effect on Paladin's operation.

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FAQ

Why do the numbers 'bounce' and the PV Totals not match the Inverter?

Paladin is not designed to be a meter as its' core task is to figure out what is happening at the Grid entry point and divert every possible Watt of excess PV to the Hot Water Cylinder. The dynamics of the electricity flow to and from a house are complex and chaotic, and depending upon the observation time frame the relationship between PV and house activity is either serene or very variable.

Paladin reads that electron stream as fast as possible to get an accurate sense of what is happening every mains cycle (one fiftieth of a second) and acts on that information in the same time scale. It also continuously changes internal values to cater for varying conditions. Paladin's short term accuracy is high; long term 'metering', not so much - by design.

With that in mind you will see the Grid values 'bouncing' since that number is updated once a second and it represents a snapshot of 1 second's worth of averaged activity. Hidden inside that 1 second number is another 50 cycles worth of activity and 3200+ grid reads.

Likewise, any totals are just an approximation of what has happened since the last reset. These numbers are definitely not absolutes and are provided for the user to get a sense of the day's progress, not as a substitute for a meter reading. Your electricity meter and PV inverter data are the correct place to look for absolute values. That said, there should not be a huge difference and any large deviations should be investigated as it could indicate a badly placed or defective CT clamp, or even some problem with Paladin itself. But again, Paladin is extremely sensitive and often 'sees' effects that are not directly associated with pure household current flow, such as minute induced changes in the house and CT wiring caused by external influences. High values of Solar radiation caused by CMEs (Coronal Mass Ejections), induction from overhead power lines and such are typical suspects.

Accuracy:

An interesting sidebar. I would never have thought that a vacuum cleaner would use more power on the forward than on the backwards stroke. But it does, and Paladin sees that. The reason is reasonably obvious once you think about it. Pushing forward, there is a downward component to the applied force, which in turn presses the cleaning head harder onto the floor; thus increasing the seal, and the effort required to spin the motor.

When do the Totals reset?

Paladin's internal clock is linked to solar activity, or more specifically to PV transfer. An hour is still an hour, but the day start time is internally 8 hours since the last PV transfer activity to the hot water cylinder. Nominally this will be around or just after midnight, but in the summer, may be as late as 4am. Since this only affects the Totals, it is of no importance to Paladin's mission, just the displayed totals. Since the totals are about transfer and (if fitted) PV output, using 'sun' time is the most practical option.

How does Paladin manage Legionnaire's Disease?

There is a health problem associated with accumulated 'nasties' that breed in water systems that run at temperatures below 50C or so for prolonged periods. The effective recommended prevention technique is to ensure that the water temperature reaches 60C at least every 72 hours. Paladin does exactly that. Whenever the water temperature reaches 60C it resets an internal counter to zero. Every hour it adds one to that counter and if the counter reaches 72 the hot water is boosted to 60C, at which point the whole cycle starts again. If you have excess PV then this activity will be rare, but there will be times when it happens - particularly in winter. Internally Paladin tries to anticipate this, and if it anticipates a potential 'health top up' occurring during day time peak hours it will forward schedule the temperature boost to 60C in the early hours of the day, just after the totals reset.

With regard to water temperatures, it should be obvious that if your hot water cylinder main thermostat is defective, not set to maximum or in some other way not able to allow a temperature of at least 60C then the health temperature sequence will effectively force Paladin to top up continuously and be totally ineffective. Likewise, if the temperature probe is incorrectly positioned a similar situation will occur. See the installation manual for details.

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Why have you changed the display format from Paladin-2?

There is another display inside Paladin-4 that is similar to Paladin-2, but with a lot more detail. It is used for diagnostics and tuning etc. However it is so complex to read and understand that it confuses everyone - even me. The display has absolutely no bearing on Paladin's mission at all; it is there because sometimes it is interesting. The present display has evolved to give what, IMHO, is a fair balance between simplicity and the amount of information that is interesting and valid relating to day to day operation.

How accurately does Paladin transfer excess PV?

There are a couple of 'IFs' associated with that answer. If your excess PV never exceeds your hot water heating element rating and you never reach 73C water temperature or your tank thermostat limit then you can expect 90%, often 95% or sometimes even better. The 'even better' bit depends very much on the type of loads that occur in the house and the gross variability of the PV output itself. Typical 'difficult' loads for Paladin to manage are high wattage irons and Induction cookers. Paladin does manage these rather well, but the very rapid surges in load that they produce can cause small amounts of 'spillage'.

Once you produce excess PV over and above what your heater element can absorb or you hit maximum temperature, excess PV will of course be exported.

DeltaT:

Paladin introduces a novel concept (for a device like this) of DeltaT - that is rate of change of temperature over time. This is largely transparent in operation, but the more eagle eyed may see its' effects. If the water temperature is dropping quickly towards minimum (40C normally) the DeltaT mechanism will see this well before the water actually reaches 40C and will start a top up sequence earlier than would be possible by just waiting for 40C to be registered. This allows Paladin to head off most cold shower situations, subject to water use and heater size etc.

Conversely, when topping up, if there is only a few degrees of temperature to change then DeltaT will not activate the heater at full power. Because DeltaT is a constantly changing relationship between present temperature and the temperature gradients over the last hour, this can often result in non intuitive top up behaviour in the short term. Dedicated Paladin watchers (and I am reliably informed that this is a thing), have commented on this. But fear not, it just works.

Why?

The why is simply that the power companies have decided, because they can, to drop the Feed-In-Tariff (FIT) to unrealistic levels. PALADIN is a push back and protection from this and a solution that works very well in almost all situations. There are some practical and basic limitations to HWC setups that can take best advantage of PALADIN's abilities:

1. A HWC of at least 180 liters (a standard tank in NZ/AUS) and a thermostat set above 73C.
2. A tempering valve that will enable the HWC water temperature thermostat to be set at more than 60C. (The hotter the water the more power it can store, and the better the buffer for cloudy days).
3. A normal use of hot water. If you are not drawing off hot water then the best that PALADIN can manage is about 1.6kWh of solar power diversion per day, as that is the magnitude of normal thermal losses (see below).
4. A 'Smart Meter'. PALADIN will work on any meter, but it works best on the 'Smarties'. If you have the old style 'spinning wheel' then you don't need this anyway since, to mangle a metaphor, that wheel spins both ways.

The average household consumes 8 to 12 kWh of electricity a day for hot water. The numbers are: (and individual mileage may vary)

A 180-liter hot water tank uses 3.15kWh of electricity to raise the water temperature by 15 degrees Celsius.

A normally insulated 180L tank uses around 1.6kWh of energy per day, in lost heat.

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The situation is this: If you have a 1:1 FIT you really don't care when your immersion heater runs. You produce the power, you use the power - the time frame is not important. However, if you are buying power at 4 times the rate you can sell it for, then it makes perfect sense to use as much of your own power as possible at the exact moment you produce it. If the Grid doesn't want your power, then the Grid doesn't get it. Absent a large battery, the only practical power storage you have in the average home is the hot water cylinder (HWC).

How

This is the slightly nerdy stuff that is definitely just 'nice to know', not 'need to know'.

Happily, everyone now has a smart meter installed. All smart-meter's work in essentially the same way. They have (conceptually), a 1Wh or 3600 joule 'power bucket' that keeps track of the energy flow. When the 'bucket' fills, for either import or export, the light flashes and the appropriate power counter goes up by 1 unit - usually 1000 units to the kWh.

If we monitor the mains feed to the house and collect data fast enough, we can accurately model the state of that 'bucket' and we can leverage that data to switch the immersion heater on and off just enough to stop the bucket filling, and consequently ticking over the meter. The key here is speed, and you can only practically switch the heater on and off on the crossing phase of the mains cycle, which is 50 times a second.

The 1Wh 'bucket' capacity is a real bonus in this sense. 1Wh doesn't sound a lot, but in other units it is 3600 Joules. This is just another, larger number. However, think about a 1kW heater running for 1 hour. In that time, it uses 1kWh (1000Wh) of energy, give or take. What about each minute? That would be $1000/60 = 16.6\text{Wh}$. What about every second? That will be $1000/3600 = 0.278\text{Wh}$. There might be 2 light bulbs above your head at this point? One will be for the 3600, which is, not by coincidence, the number of seconds in an hour and also the number of Joules in a Watt. The second, and most important, is that the power use on a 1kW heater every second is a fraction of the 1Wh of the 'bucket'. Even a large 3kW immersion heater uses less than 1 Watt per second. How convenient is that?

PALADIN can control your heater on and off up to 50 times per second (Hz), at the mains frequency. Additionally, it is monitoring the mains flow, over 60 times per mains cycle - which is >3000 times per second. Practically this is way in excess of the accuracy of the support circuitry such as the current clamps, but why not?

So a simple metaphor for PALADIN's operation would be a water tank, filled by your solar at a variable rate dependant on the panel output, and emptied by the amount of power use in the home. At the bottom of the tank is a large tap that represents your immersion heater. PALADIN watches, calculates and waits until the tank is half full, it then opens the tap to the heater. Depending upon the rate of input flow, the tank either begins to empty or continues to fill. If the tank starts to empty then the tap gets turned off. Otherwise it stays on for another cycle. If the solar input exceeds the tank capacity and the flow to the heater then it will eventually fill and you will just have to export that Watt of power, and the cycle starts again.

In practice, if you have a solar array that is significantly larger than your heater and not much power use in the house in the middle of a summer's day, you are going to export power. But only the remainder and it is unavoidable. The good news is that this doesn't happen that often because of the shape of the solar curve. You will also be forced to export if your tank temperature reaches maximum, obviously.

At this point, just to stay a little nerdy, it is well to mention that PALADIN is not perfect. Despite a very high sampling rate and high-quality sensors, the vagaries of inductive loads, such as the motors / compressors on refrigerators and freezers, power tools and heat exchangers etc, do cause PALADIN to miss the odd Watt here and there. In practice, this can be around 5% of excess PV per day in unintended export. This depends on your household use, the variability of the sunshine and the quality of your house wiring.

But to put that in perspective on the same day you will have diverted all the rest to your immersion heater.

One finger in the air to the power company.

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Version 624 and onward

There are installations that do not need or want to use a temperature probe, and in normal operations Paladin does need that temperature feedback from the hot water tank to operate effectively. Should the temperature probe be damaged, incorrectly wired or just not fitted, there is a self check mechanism now built into the start up sequence. If your probe is correct and sending valid temperatures, then you will NOT see the following:

If the probe is not fitted or not working, the start-up sequence will be protracted whilst a full check is carried out. This takes about 20 seconds and the screen indicates marching '>>>'. A failure puts Paladin into a NO TEMP mode. This is documented below, but it is quite safe to use Paladin in this mode for a few days pending repairs or replacement. You will have 'NO TEMP' replacing Paladin on the screen and no temperature values on the display. All other diversion functions are as normal.

Paladin-6 V626 and onward

When Paladin starts you see the software version on the screen. It is also attached to a label on the side. If you have a unit with version 626 or greater then there are a few more extras to be aware of.

All Paladin4's with software 624 or greater are Paladin-6 ready. That is by just changing the little daughter board that sits on top of the main CPU, you get all sorts of extra goodies. But that is scheduled for late 2018. In the meantime you (may) have a switch on the left hand side of the case. This switch has 3 positions. UP - OFF - DOWN. This is what it does:

OFF = Center: Nothing at all.

UP = 60C Boost: With the switch in the UP position Paladin will boost the water temperature to 60C in the small hours of the morning, during the reset cycle. Depending upon the quality of your tank insulation this will leave you water temperature at around 58C for morning showers etc, to avoid topping up on peak power. If the water is already above 60C when the daily reset occurs, then nothing happens. Changing the switch position anytime before reset removes this behavior. Leaving the switch UP repeats the sequence daily.

With the switch in the UP position the 'C' appending the displayed water temperature changes to 'B'. Since this portion of the display only changes every 6 seconds - be patient.

DOWN = Minimum Temperature Changed to 50C: Putting the switch DOWN immediately changes the minimum temperature setting to 50C (from 40C). This change will persist as long as the switch stays down. If the water temperature is below 50C then you will start heating. This is an immediate response (6 seconds max), so you will see the results as a top up message and a transfer. Returning the switch to OFF or UP will return the Minimum Temperature to 40C.

With the switch in the DOWN position the 'C' appending the displayed water temperature changes to '^'. Since this portion of the display only changes every 6 seconds - be patient.

Diagnostic Display

If you (re)start Paladin with the side switch (if fitted) in the DOWN position the display will change to the Diagnostic Mode. This display is really for myself and the factory to use for testing and tuning. However, since it is inevitable that because the side switch can access this, albeit obliquely - someone will. To avoid writing 'DON'T PANIC' in large friendly letters on the screen, here is decode and explanation of what can be seen.

Line 1

Is the same as the normal display. Temperature / Messages and Graphic / Transfer Time

Line 2

Becomes three blocks of numerals. Grid I/O (Neg = Input) / Total In / Total Export

Line 3

Is likewise three blocks of numerals. Transfer Now / Total Transfer / Total Top Up

Line 4

As above (if fitted). PV Now / PV Total.

The last element of the 4th line (bottom right) displays different values depending upon the minute value of the internal clock. On the ODD minutes it will show the minimum temperature setting as adjusted by DeltaT or the switch (so in this case it will show (M)50). On EVEN minutes it shows the grid reads per second. This will range between 3000 and 4000 depending upon internal processes. Values below 3000 are indicative of a poor CPU timing crystal. (Which is why it is there). You will also see a set of '00000's alternating with the above. This is the DeltaT variance, but since use of the 50C switch to activate this effectively disables DeltaT for the duration of this 'boost', the values are zeros.

All this is of absolutely no interest at all to the end user, and is provided just to satisfy the curious.

Moving the switch to any other position will revert the screen to normal operations.

Enjoy and save Solar.....

KBS – Paladin Developer and Technical Director (Auckland, August 2018)