Title: **CONFIGURATION OF THE HARVESTING PARAMETERS**

Product Family: **EM850X**

Part Number: EM8500

Keywords: Harvesting, Solar, TEG, MPPT, Configuration, Setup

ABSTRACT

The EM8500 offers a NVM containing all the configuration parameters. This document describes how to setup the registers in NVM linked to the harvester:

- Type of harvester: Thermal Electrical Generator or Solar cell.
- MPPT algorithm configuration
- Timings and levels related to the harvester power capability

ABBREVIATIONS

NVM	Non-Volatile-Memory
MCU	Microcontroller Unit
STS	Short term storage element (capacitor connected to VDD_STS)
LTS	Long term storage element (rechargeable battery connected to VDD_LTS)
HRV	Harvester, main source of energy (solar or TEG)
TEG	Thermal Electrical Generator
MPP	(Maximum Power Point) This operating point is reached when the harvester delivers the maximum power (Pmpp) in a given condition
Vmpp	HRV output voltage when at MPP
Vmpp_min	Vmpp limit under which the HRV_LOW mode shall be activated
Impp	HRV output current when at MPP
Pmpp	HRV output power when at MPP
Vov	HRV open voltage (when the EM8500 DCDC converter is disabled)
Vov_min	HRV open voltage corresponding to Vmpp_min
BAT_LOW	Flag indicating that the battery is in under-voltage condition
HRV_LOW	Flag indicating that the HRV is under the minimum power level (HRV low mode when at 1)
Vhrv_scv	HRV voltage reference for short-circuit current measurement (70mV)
Vlvl	Voltage level detector LSB (73 mV)
NVM	Non-Volatile-Memory
MCU	Microcontroller Unit
STS	Short term storage element (capacitor connected to VDD_STS)
LTS	Long term storage element (rechargeable battery connected to VDD_LTS)
HRV	Harvester, main source of energy (solar or TEG)

1 SCOPE

The EM8500 addresses two main types of HRV:

1. Solar cells
2. TEG (Thermal Electrical Generator)

The EM8500 has several parameters to setup the HRV depending on its type, its power range and its voltage range. Two main functions shall be setup:

1. Harvest energy at the MPP (Maximum Power Point)
2. Stop harvesting energy when the power available is too low.

The following registers are involved for that action:

Register name	Address	Description
reg_t_hrv_period	0x00	Define the period between two HRV checks when DCDC is operating
reg_t_hrv_low_cfg	0x17	*t_hrv_low_period*: Define the period between two HRV checks in HRV low mode
reg_t_hrv_meas	0x01	Define the duration of the HRV sampling phase
reg_v_hrv_cfg	0x04	*hrv_check_vld*: Set the type of HRV (1 for a TEG ; 0 for a solar cell) *v_hrv_min*: set the minimum open voltage level (used for TEG in operating mode and Solar Cell in HRV low mode)
reg_hrv_check_lvl	0x05	Set the minimum short-circuit current level (used for Solar Only)
reg_mppt_ratio	0x12	Set the HRV voltage ratio between open and loaded to operate @MPP

Table 1: List of Registers Related to Harvesting Parameters

The default value after reset or start-up of the registers listed in Table 1 is contained in a NVM memory at the following related addresses:

Register name	Register Address	Related address in NVM	
reg_t_hrv_period	0x00	eeprom0	0x40
reg_t_hrv_low_cfg	0x17	eeprom23	0x57
reg_t_hrv_meas	0x01	eeprom1	0x41
reg_v_hrv_cfg	0x04	eeprom4	0x44
reg_hrv_check_lvl	0x05	eeprom5	0x45
reg_mppt_ratio	0x12	eeprom18	0x52

Table 2: Relation between Register and Corresponding NVM Address

Note: offset between the register addresses and related address in NVM is 0x40

2 HRV CONFIGURATION SEQUENCE

2.1 MPPT setting

The MPPT is the algorithm to find the point where the power is maximum along a V=f(I) curve. For each type of HRV, there is a ratio between the loaded (Vmpp) and open voltage (Vov) where the power is maximum (MPP). The EM8500 DCDC regulates the voltage VDD_HRV to be equal to Vmpp. This ratio is set by the register *reg_mppt_ratio* as follows:

reg_mppt_ratio **[hex]**	**MPPT ratio [%]**
0x00	50
0x01	60
0x02	67
0x03	71
0x04	75
0x05	78
0x06	80
0x07	82
0x08	83
0x09	85
0x0A	86
0x0B	87
0x0C to 0x0F	88

Table 3: MPPT Ratio Selection

The EM8500 samples Vov * MPPT ratio and holds that value in an internal capacitor. The DCDC converter regulates VDD_HRV to be equal to the hold value. When this condition is fulfilled, the maximum power is transferred into the charge.

2.1.1 MPPT for a TEG

The TEG has a pure ohmic impedance and therefore a linear V=f(I) curve as follows:

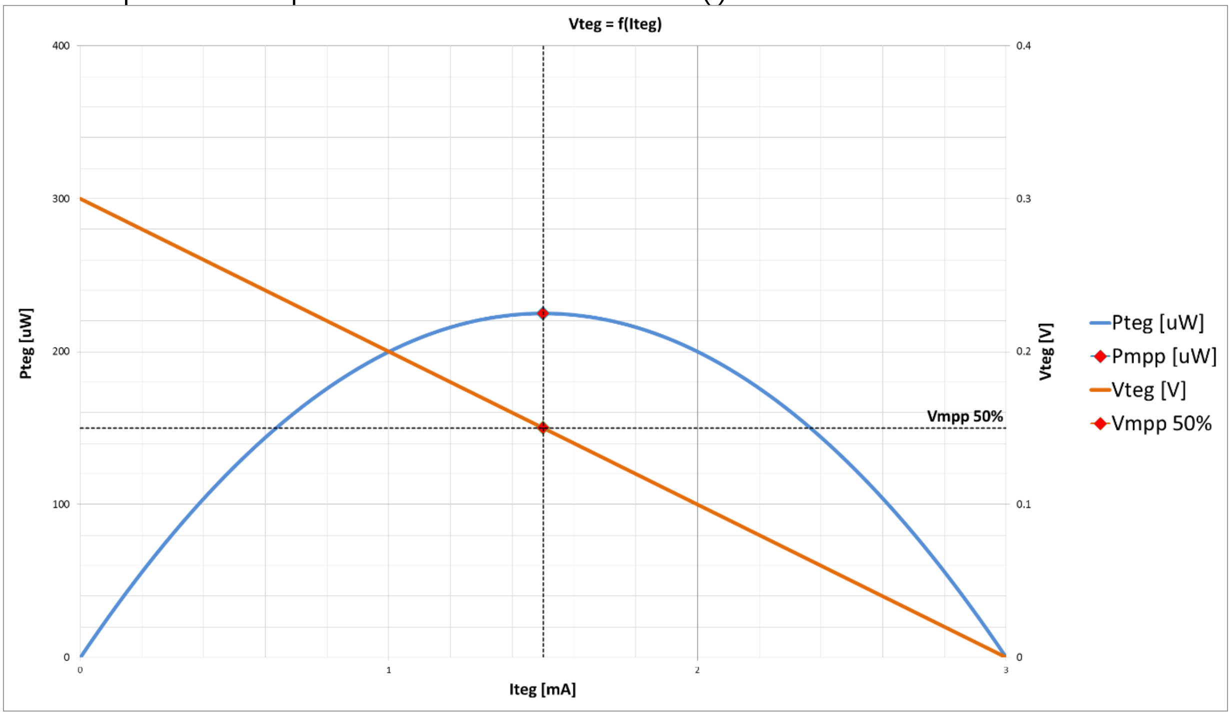

Figure 1: V=f(I) Curve of a TEG

The MPP is reached when the loaded voltage is 50% of the open voltage (Vteg = Vmpp). The register *reg_mppt_ratio* shall be set to 0x00 when EM8500 harvests energy from a TEG.

2.1.2 MPPT for a solar cell

The solar cell has a non-linear V=f(I) curve as follows:

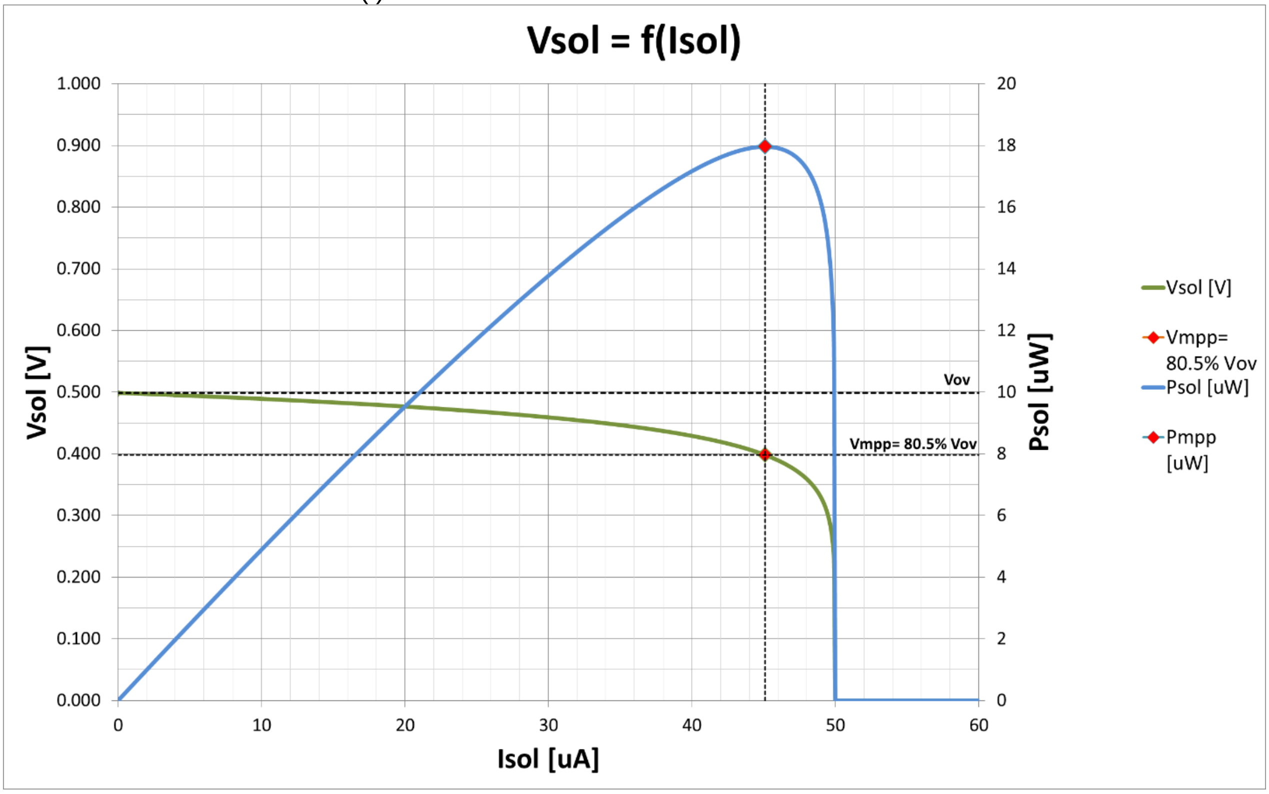

Figure 2: V=f(I) Curve of a Solar Cell

The MPP is reached when the loaded voltage is around 80% of the open voltage (Vsol = Vmpp). Depending on the type of solar cell, the power range or the temperature, Vmpp can be slightly different than 80%. The EM8500 offers other ratios around 80% as shown in the Table 3. Typically, the register *reg_mppt_ratio* shall be set to 0x06 when the EM8500 harvests energy from a solar cell.

2.2 HRV check settings

The EM8500 regularly checks if the HRV can generate energy. When this is not the case the EM8500 stops the DCDC converter and sets the flag HRV_LOW to '1'. There 2 ways to check the HRV capability:

- Measure the open voltage of the HRV: *reg_v_hrv_cfg.hrv_check_vld* = 1 (preferably for TEG)
- Measure the short-cut current of the HRV: *reg_v_hrv_cfg.hrv_check_vld* = 0 (preferably for Solar)

2.2.1 HRV open voltage measurement

The HRV open voltage measurement method is active when: *reg_v_hrv_cfg.hrv_check_vld* = 1
This technique is used mainly for harvesters having a high voltage swing from worst to best conditions. It is clearly the case for a TEG. The open voltage grows linearly with the temperature proportionally to the Seebeck coefficient:

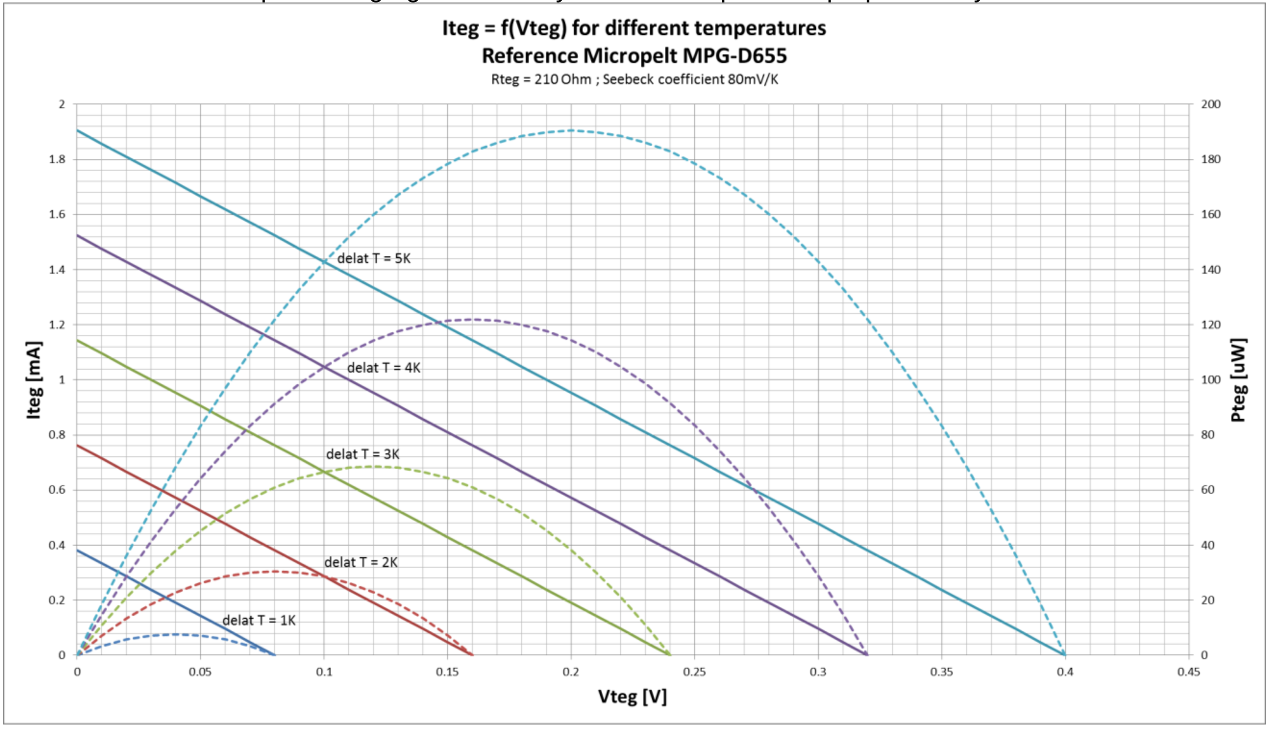

Figure 3: V=f(I) Curve of a MPG-D655 for Different Delta Temperatures

The maximum power that a TEG can deliver, at a given open voltage, depends on its internal resistivity. It can be calculated using the following equation:

$$P_{mpp\_max} = \frac{V_{ov}^{\ 2}}{4 \cdot R_{teg}}$$

Equation 1: Maximum Power Delivered by a TEG over Vov and Rteg

The minimum power the EM8500 can harvest depends on the input voltage delivered by the HRV and the output voltage that the DCDC converter shall deliver to VDD_LTS. Then, there is a relation between the internal resistivity of the TEG, the minimum Vov to harvest and the DCDC converter output voltage range as shown in the following table:

	Maximum TEG internal resistivity		
	Vout range 1.5V to 2V	**Vout range 2V to 3V**	**Vout range 3V to 3.6V**
v_hrv_min = 0x02 Open voltage level 216mV	830 Ohm	410 Ohm	80 Ohm
v_hrv_min = 0x03 Open voltage level 288mV	2980 Ohm	1490 Ohm	290 Ohm
v_hrv_min = 0x04 Open voltage level 359mV	7770 Ohm	3880 Ohm	1160 Ohm
v_hrv_min = 0x05 Open voltage level 431mV	16780 Ohm	8390 Ohm	3350 Ohm

Table 4: Maximum TEG Resistivity Related to *v_hrv_min* and Vov Range

According to the Table 4, if the TEG MPG-D655 with a resistivity of 210 ohm is used, *v_hrv_min* shall be set to 0x02 if the maximum battery voltage is in the range 1.5V to 2V or 2V to 3V. If the maximum battery voltage is in the range 3V to 3.6V, *v_hrv_min* shall be set to 0x03.

2.2.2 HRV short-cut current measurement

The HRV short-cut measurement method is active when: *reg_v_hrv_cfg.hrv_check_vld* = 0
As shown in the Figure 4, the light strength affects the current capability more than the open voltage of a solar cell. The output current capability of a solar cell is more or less linear with the light strength.

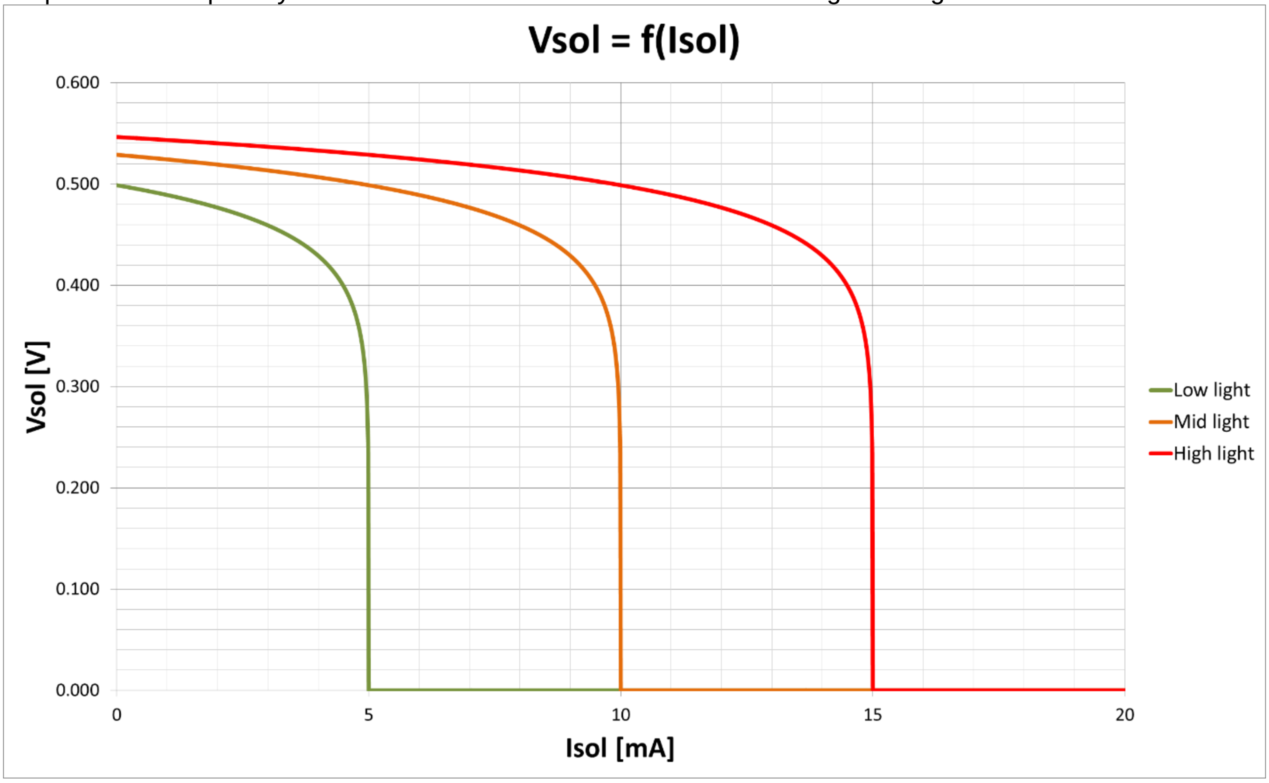

Figure 4: V=f(I) Solar Cell Curves for Different Light Strengths

The EM8500 uses the function "HRV check" to determine if the solar cell current capability is above or below a certain level. It loads the HRV with a resistor and compares the loaded voltage Vsol with a typical reference value, Vhrv_scv (70mV). If Vsol is lower than this reference, the EM8500 considers the HRV too weak to deliver energy, stops the DCDC converter and sets the flag HRV_LOW to '1'.
In HRV low mode (HRV_LOW = 1), in order to save energy the voltage reference Vhrv_scv is not available. The reference of the voltage level detector measuring the HRV open voltage is used instead. Therefore the register *v_hrv_min* shall be set 0x01 (Vlvl = 146mV) when the short-cut measurement method is set.

The minimum power the EM8500 can harvest depends on the input voltage delivered by the HRV and the output voltage that the DCDC converter shall deliver to VDD_LTS. Then, there is a relation between the output current capability of the solar cell, the minimum Vmpp and the DCDC converter output voltage range as shown in the following table:

	reg_hrv_check_lvl		
	Vout range 1.5V to 2V	**Vout range 2V to 3V**	**Vout range 3V to 3.6V**
Vmpp_min = 0.2 (Vov_min = 0.25 @80%)	**0x0A** Ihrv_lim = 11uA	N.A.	N.A.
Vmpp_min = 0.3 (Vov_min = 0.38 @80%)	**0x03** Ihrv_lim = 4uA	**0x07** Ihrv_lim = 8uA	**0x0E** Ihrv_lim = 15uA
Vmpp_min = 0.4 (Vov_min = 0.50 @80%)	**0x02** Ihrv_lim = 3uA	**0x05** Ihrv_lim = 6uA	**0x08** Ihrv_lim = 9uA
Vmpp_min = 0.5 (Vov_min = 0.63 @80%)	**0x02** Ihrv_lim = 3uA	**0x02** Ihrv_lim = 3uA	**0x04** Ihrv_lim = 5uA
Vmpp_min = 0.6 (Vov_min = 0.75 @80%)	**0x01** Ihrv_lim = 2uA	**0x01** Ihrv_lim = 2uA	**0x03** Ihrv_lim = 4uA
Vmpp_min = 0.7 (Vov_min = 0.88 @80%)	**0x01** Ihrv_lim = 2uA	**0x01** Ihrv_lim = 2uA	**0x03** Ihrv_lim = 4uA
Vmpp_min = 0.8 (Vov_min = 1.00 @80%)	**0x01** Ihrv_lim = 2uA	**0x01** Ihrv_lim = 2uA	**0x02** Ihrv_lim = 3uA
Vmpp_min = 0.9 (Vov_min = 1.13 @80%)	**0x01** Ihrv_lim = 2uA	**0x01** Ihrv_lim = 2uA	**0x02** Ihrv_lim = 3uA
Vmpp_min = 1.0 (Vov_min = 1.25 @80%)	**0x01** Ihrv_lim = 2uA	**0x01** Ihrv_lim = 2uA	**0x02** Ihrv_lim = 3uA
Vmpp_min = 1.1 (Vov_min = 1.38 @80%)	**0x00** Ihrv_lim = 1uA	**0x00** Ihrv_lim = 1uA	**0x01** Ihrv_lim = 2uA
Vmpp_min = 1.2 (Vov_min = 1.50 @80%)	**0x00** Ihrv_lim = 1uA	**0x00** Ihrv_lim = 1uA	**0x01** Ihrv_lim = 2uA
Vmpp_min = 1.3 (Vov_min = 1.63 @80%)	**0x00** Ihrv_lim = 1uA	**0x00** Ihrv_lim = 1uA	**0x01** Ihrv_lim = 2uA
Vmpp_min = 1.4 (Vov_min = 1.75 @80%)	**0x00** Ihrv_lim = 1uA	**0x00** Ihrv_lim = 1uA	**0x01** Ihrv_lim = 2uA
Vmpp_min = 1.45 (Vov_min = 1.80 @80%)	**0x00** Ihrv_lim = 1uA	**0x00** Ihrv_lim = 1uA	**0x01** Ihrv_lim = 2uA

Table 5: HRV Check Level Selection Related to Minimum Vmpp and Output Voltage Range

Vmpp_min means Vmpp at lower light condition. For instance, the solar cell in Figure 4 at lower light condition, Vmpp is around 0.4V. If the battery voltage connected to VDD_LTS is within the range 3V to 3.6V, the register *reg_hrv_check_lvl* shall be set to at least 0x08.
The following equation defines the relation between Ihrv_lim and the register *reg_hrv_check_lvl*:

$$I_{hrv\_lim} = 1\mu A \cdot (reg\_hrv\_check\_lvl + 1)$$

Equation 2: Ihrv_lim over Register *reg_hrv_check_lvl*

2.2.3 HRV check timing settings

The user can configure the period of the HRV check. If the HRV open voltage measurement method is used, the sample & hold required for MPPT measurement is done in the same time as the HRV check. Otherwise, when the short-cut current method is used, the sample & hold is done alternatively with the HRV check; the sample & hold is done on Vov but the current measurement is done on short-cut voltage.
The sample & hold and the open voltage measurement last a certain duration to allow Chrv to charge up to Vov. This duration is configurable with the register *reg_t_hrv_meas*. When a TEG is used, we advise setting a duration in accordance with the Equation 3:

$$T_{hrv\_meas} = 5 \cdot R_{teg} \cdot C_{hrv}$$

Equation 3: Min Thrv_meas Calculation for a TEG

For the TEG this duration does not depends on Vov, but only on the internal resistivity and Chrv.
Concerning the solar cell, we consider that in the worst case condition Chrv is charged up to Vov (Vmpp / 0.8) with the current set by the register *reg_hrv_check_lvl* in Table 5 multiplied by 2.5 as margin. This margin is required to compensate the fact that the current Isol is not constant all along Vsol:

$$T_{hrv\_meas} = \frac{2.5 \cdot (V_{ov\_\min} - V_{pp\_\min}) \cdot C_{hrv}}{I_{hrv\_lim}}$$

Equation 4: Min Thrv_meas Calculation for a Solar Cell

When the HRV check is done by the short-cut measurement method, the measurement duration is constant: 64ms. The HRV measurement and the sampling & hold impact the global efficiency of the transfer of energy. To reduce this impact, it is important to have a duty-cycle between the HRV measurement phase and the harvesting phase low enough. During the sampling phase or the HRV check measurement, no energy is transferred into the charge. The loss of efficiency is therefore:

$$Eff_{loss} = \frac{T_{hrv\_meas}}{T_{hrv\_period}}$$

Equation 5: Efficiency Loss Due to HRV Check & Sampling Phase

On other hand, if **Thrv_period** is too long, the MPPT could be detuned if the harvesting conditions quickly change. Considering a solar application, if the light is blinking with a period shorter than **Thrv_period**, the MPPT reference will not be adapted all the time.
When the conditions change slowly we advise selecting the longest **Thrv_meas** that the sample & hold can afford (i.e. **32s**). If the conditions quickly change, the shortest **Thrv_period** with an acceptable efficiency loss shall be selected. If a period of 2048ms is selected with 64ms sampling phase, the efficiency loss is 3%.

2.2.4 HRV check in HRV low mode

In HRV low mode (HRV_LOW = 1), there is no sampling and hold done but only the HRV check using the voltage level detector. In this condition, **Thrv_period** is defined by the register *reg_t_hrv_low_cfg.t_hrv_low_period* instead of the register *reg_t_hrv_period*.
The selection of **Thrv_meas** and **Thrv_period** is done with the related register *t_hrv_meas*, *t_hrv_period* and *reg_t_hrv_low_cfg.t_hrv_low_period* as follows:

Register value	Thrv_meas (register : *t_hrv_meas*)	Thrv_period (register : *t_hrv_period* ; HRV_LOW = 0) (register : *t_hrv_low_period* ; HRV_LOW = 1)
000	16ms	256ms
001	32ms	512ms
010	64ms	1s
011	128ms	2s
100	256ms	4s
101	512ms	8s
110	1s	16s
111	2s	32s

Table 6: Thrv_meas and Thrv_period Related Registers

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