Introduction

The STPMC1 device functions as an energy calculator and is an ASSP designed for effective energy measurement in power line systems utilizing Rogowski coil, current transformer, and Shunt or Hall current sensors. Used in combination with one or more STPMSx ICs, it implements all the functions needed in a 1, 2, or 3-phase energy meter.

Due to its internal structure and features, STPMC1 allows a more effective and innovative calibration procedure, which is explained in this document.

Advantages of this procedure are:
- reduced calibration time
- no need for re-calibration (calibration parameter can be written in a permanent way).

For further information about the device please refer to the STPMC1 datasheet.

This application note integrates the AN2299 application note for the STPMC1 metering chip. Sections 1, 2, and 3.1 of the AN2299 application note can be considered valid also for the STPMC1 device, sharing the same architecture as STPM01 and STPM10 devices, whilst the calibration calculations shown in section 3.2 of AN2299 and in this document are slightly different and are reported below.
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1 Calibration flow chart

The calibration procedure can be summarized in the following steps, which are examined in Section 1.1.

![Calibration flow chart](image)

Figure 1. Calibration flow chart

1. Working point setting
2. Algorithm choice
3. Offline parameters calculations
4. Online procedure (for each phase)
5. Coherency check (for each phase)

1.1 Calibration procedure

1.1.1 Working point setting

According to the information contained in AN2299, the STPMC1 device can also be calibrated in a single point for each phase.

Therefore, voltage and current nominal values of the selected phase must be defined before running the calibration procedure, for example:
The other parameters, which follow, and the constants of the STPMC1 metering device (and relative tolerances) are also known:

**Table 1. Working point setting**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_n$</td>
<td>230 V</td>
<td>Phase to neutral RMS voltage</td>
</tr>
<tr>
<td>$I_n$</td>
<td>5 A</td>
<td>Phase RMS current</td>
</tr>
</tbody>
</table>

**Table 2. STPMC1 internal parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_V$</td>
<td>0.875</td>
<td>Voltage calibrator ideal value if $PM = 0^{(1)}$</td>
</tr>
<tr>
<td></td>
<td>0.9375</td>
<td>Voltage calibrator ideal value if $PM = 1$</td>
</tr>
<tr>
<td>$K_I$</td>
<td>0.875</td>
<td>Current calibrator ideal value if $PM = 0$</td>
</tr>
<tr>
<td></td>
<td>0.9375</td>
<td>Current calibrator ideal value if $PM = 1$</td>
</tr>
<tr>
<td>$\text{len}_i$</td>
<td>$2^{16}$</td>
<td>Current register length</td>
</tr>
<tr>
<td>$\text{len}_u$</td>
<td>$2^{12}$</td>
<td>Voltage register length</td>
</tr>
<tr>
<td>$K_{\text{int_comp}}$</td>
<td>1.004</td>
<td>Gain of decimation filter</td>
</tr>
<tr>
<td>$\pi$</td>
<td>3.14159</td>
<td></td>
</tr>
<tr>
<td>$F_M$</td>
<td>$4 \times 10^6$</td>
<td>If oscillator frequency is 4.000 or 8.000 MHz</td>
</tr>
<tr>
<td></td>
<td>$2^{22}$</td>
<td>If oscillator frequency is 4.194 or 8.388 MHz</td>
</tr>
<tr>
<td></td>
<td>4915200</td>
<td>If oscillator frequency is 4.915 or 9.830 MHz</td>
</tr>
<tr>
<td>$D_{UD}$</td>
<td>$2^{17}$</td>
<td>Internal parameter</td>
</tr>
<tr>
<td>$V_{\text{ref}}$</td>
<td>1.23</td>
<td>Internal voltage reference</td>
</tr>
<tr>
<td>$A_u$</td>
<td>4</td>
<td>Amplification of voltage ADC for STPMS1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Amplification of voltage ADC for STPMS2</td>
</tr>
<tr>
<td>$A_i$</td>
<td>8</td>
<td>Amplification of current ADC for STPMS1</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>Amplification of current ADC for STPMS1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Amplification of current ADC for STPMS2</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>$K_{\text{int}}$</td>
<td>0.815</td>
<td>Gain of integrator @ line frequency = 50 Hz</td>
</tr>
<tr>
<td></td>
<td>0.679</td>
<td>Gain of integrator @ line frequency = 60 Hz</td>
</tr>
<tr>
<td>$K_{\text{dif}}$</td>
<td>0.6135</td>
<td>Gain of differentiator @ line frequency = 50 Hz</td>
</tr>
<tr>
<td></td>
<td>0.7359</td>
<td>Gain of differentiator @ line frequency = 60 Hz</td>
</tr>
</tbody>
</table>

1. PM is CFG 21, which sets the meter precision (Class 1 or Class 0.1).
Only analog parameters are objects of calibration because they introduce a certain error. Voltage ADC amplification $A_v$ is constant, while $A_i$ is chosen according to the used sensors.

The calibration procedure has, as a final result, correction parameters called $K_{VR}$, $K_{VS}$, $K_{VT}$ and $K_{IR}$, $K_{IS}$, $K_{IT}$ and $K_{IN}$ (if used) which, applied to STPMC1 voltage and current measurements, compensate small tolerances of analog components that affect energy calculations.

As $K_{VR}$, $K_{VS}$, $K_{VT}$ and $K_{IR}$, $K_{IS}$, $K_{IT}$ and $K_{IN}$ calibration parameters are the decimal representation of the corresponding configuration bytes $CVR$, $CVS$, $CVT$ and $CIR$, $CIS$, $CIT$, $CIN$, the values of those bits are obtained at the end of calibration.

In the following procedure $CVR$, $CVS$, and $CVT$ are indicated as $Cv$; $CIR$, $CIS$, $CIT$, and $CIN$ are indicated as $Ci$; $K_{VR}$, $K_{VS}$, and $K_{VT}$ are indicated as $Kv$, and $K_{IR}$, $K_{IS}$, $K_{IT}$, and $K_{IN}$ are indicated as $Ki$.

Through hardwired formulas, $Kv$ and $Ki$ tune measured values varying from 0.75 to 1 in 256 steps, according to the value of $Cv$ and $Ci$ (from 0 to 255).

If PM=1, two bits are appended to each $Cv$ and $Ci$ (see the STPMC1 datasheet for details), and the corresponding tunings vary from 0.875 to 1 in 1024 steps.

To initially obtain the greatest correction dynamic, calibrators are set in the middle of the range, therefore obtaining a calibration range of $\pm$ 12.5% ($\pm$ 6.25% when PM is set) per voltage or current channel:

$$K_{v,i} = \frac{C_{v,i}}{128} \times 0.125 + 0.75$$

$$C_{v,i} = 1024 \times K_{v,i} - 768$$

or when $PM = 1$

$$K_{v,i} = \frac{C_{v,i}}{512} \times 0.0625 + 0.875$$

$$C_{v,i} = 512 \times K_{v,i} - 768$$

In this way it is possible to tune $Kv$ and $Ki$ having a precise measurement: for example, with $PM=0$, $Cv=0$ generates a correction factor of $-12.5\%$ ($Kv=0.75$) and $Cv=255$ determines a correction factor of $+12.5\%$ ($Kv=1$), and so on.

According to the information above, the following formulas, which relate $Kv,i$ and $Cv,i$ to each other are obtained:

**Equation 1**

$$Kv,i = (Cv,i/128) \times 0.125 + 0.75$$

**Equation 2**

$$Cv,i = 1024 \times Kv,i - 768$$

or when $PM = 1$

**Equation 3**

$$Kv,i = (Cv,i/512) \times 0.0625 + 0.875$$

**Equation 4**
Cv,i = 8192 * Kv,i - 7168

Indicating, with AvI and AvV, the average values read from the device and with X_i and X_v the ideal values of RMS current and voltage readings, the following can be reported:

PM = 0:

**Equation 5**
\[ X_v = \frac{(Kv \times AvV)}{0.875} \]

**Equation 6**
\[ X_i = \frac{(Ki \times AvI)}{0.875} \]

PM = 1:

**Equation 7**
\[ X_v = \frac{(Kv \times AvV)}{0.9375} \]

**Equation 8**
\[ X_i = \frac{(Ki \times AvI)}{0.9375} \]

### 1.1.2 Algorithm choice

It is possible to use two different algorithms to calculate the parameters to be used during calibration:

1. \( R_1 \) and \( R_2 \) constant in order to carry out the sensor sensitivity \( K_S \)
2. Current sensor sensitivity and \( R_2 \) constant in order to carry out \( R_1 \).

The methods are the same and the choice is left to the designer.

According to the chosen algorithm, the next calibration step produces the value of sensor \( K_S \) or resistor \( R_1 \) to be mounted on the measurement board to achieve calibration.

Algorithm formulas are reported below for both current transformer/Shunt and Rogowski coil current sensors.

### 1.1.3 Offline parameter calculations

First of all, it is necessary to determine the target power sensitivity (from the LED pin) to be achieved with the calibration process, for example:

\( C = 128000 \) pulses/kWh

The calibration procedure outputs \( Cv \) and \( Ci \) values that allow the above power sensitivity of the meter.

This sensitivity is used to calculate target frequency at the LED pin for nominal voltage and current values:

**Equation 9**
\[ X_F = f \times 64 \]

with:

**Equation 10**
\[ f = \left( \frac{C}{64} \times In \times Vn \right) / 3600000 \]

**Current transformer or Shunt - Constant R₁**

In this algorithm voltage divider sensitivity is fixed, therefore, resistor values \( R₁ \) and \( R₂ \) are the known values of the voltage divider resistor.

From the values above and for both the given amplification factor \( Aᵢ \) and the initial calibration data, the following target values can be calculated:

Voltage divider output:

**Equation 11**

\[ V_{DIV} = Vn \times R₂ / (R₁ + R₂) \]

Target RMS reading for given \( Vn \):

**Equation 12**

\[ X_V = \left( \frac{V_{DIV}}{V_{REF}} \right) \times 2 \times K_{dif} \times A_v \times K_v \times K_{int\_comp} \times K_{int} \times len_u \]

Target RMS reading for given \( In \):

**Equation 13**

\[ X_I = f \times len_u \times len_i \times D_{UD} / (F_M \times X_V) \]

From which current sensor sensitivity \( K_S \) is obtained:

**Equation 14**

\[ K_S = X_I \times V_{REF} \times 1000 / (In \times A_i \times K_i \times K_{int\_comp} \times K_{int} \times K_{dif} \times len_i) \text{ [mV/A]} \]

**Current transformer or Shunt - Constant KS**

In this case the type of current sensor and its nominal value of sensitivity must be known and is equal to \( K_S \).

From the values above and for both the given amplification factor \( Aᵢ \) and the initial calibration data, the following target values can be calculated:

Target RMS reading for given \( In \):

**Equation 15**

\[ X_I = \ln \times K_S \times A_i \times K_i \times K_{int\_comp} \times K_{dif} \times len_i / (V_{REF} \times 1000) \]

Target RMS reading for given \( Vn \):

**Equation 16**

\[ X_V = f \times len_u \times len_i \times D_{UD} / (F_M \times X_i) \]

Voltage divider output:

**Equation 17**

\[ V_{DIV} = X_V \times V_{REF} / (2 \times K_{dif} \times A_v \times K_v \times K_{int\_comp} \times K_{int} \times len_u) \]

From which \( R₁ \) resistor value is obtained:

**Equation 18**
R₁ = R₂ * (Vn - VDIV) / VDIV [Ohm]

**Rogowski coil - Constant R₁**

As before, the voltage divider sensitivity is fixed, therefore, resistor values R₁ and R₂ are the known values of the voltage divider resistor.

From the values above and for both the given amplification factor Ai and the initial calibration data, the following target values can be calculated:

Voltage divider output:

**Equation 19**

\[ V_{DIV} = Vn \cdot R₂ / (R₁ + R₂) \]

Target RMS reading for given Vn:

**Equation 20**

\[ X_V = \frac{V_{DIV}}{V_{REF}} \cdot Av \cdot Kv \cdot K_{int\_comp} \cdot len_u \]

Target RMS reading for given In:

**Equation 21**

\[ X_I = f \cdot len_u \cdot len_i \cdot D_{UD} / (FM \cdot X_V) \]

From which current sensor sensitivity \( K_S \) is obtained:

**Equation 22**

\[ K_S = X_I \cdot V_{REF} \cdot 1000 / (ln \cdot Ai \cdot Ki \cdot K_{int\_comp} \cdot Kint \cdot len_i) \ [mV/A] \]

**Rogowski coil - Constant K_S**

The sensor's nominal value of sensitivity must again be known, for example, it is \( K_S \).

From the values above and for both the given amplification factor Ai and the initial calibration data, the following target values can be calculated:

Target RMS reading for given In:

**Equation 23**

\[ X_I = ln \cdot K_S \cdot Ai \cdot Ki \cdot K_{int\_comp} \cdot len_i / (V_{REF} \cdot 1000) \]

Target RMS reading for given Vn:

**Equation 24**

\[ X_V = f \cdot len_u \cdot len_i \cdot D_{UD} / (FM \cdot X_I) \]

Voltage divider output:

**Equation 25**

\[ V_{DIV} = X_V \cdot V_{REF} / (Av \cdot Kv \cdot K_{int\_comp} \cdot len_u) \]

From which R₁ resistor value is obtained:

**Equation 26**
R₁ = R₂ * (Vn - VDIV) / VDIV [Ohm]

1.1.4 Online procedure

According to the used current sensor and the chosen algorithm, a component (resistor or current sensor) of the value calculated through the formulas above must be mounted on the board.

To start the online calibration procedure, the following must be verified:

- EM is connected to the calibration system and is properly configured according to the chosen application
- EM calibrator parameters are preset to initial data
- Target values of line signals are stable.

A 3-phase voltage signal must be provided to all phases and current signal only to the phase under calibration.

When the system is connected and powered on, a certain number of readings of the RMS values must be performed.

Due to the fact that 0.4% of ripple is present in the measured RMS values, more than ten readings of these values should be gathered each cycle (20 ms at 50 Hz) and the average values of RMS current and voltage readings AvI and AvV should be computed. Consequently, having the average values AvI and AvV, a pair of final 8-bit (or 10-bit if PM = 1) calibration data can be calculated as shown below:

**Equation 27**

\[ Ci,v = 896 \times X_{I,V} / AvI, V - 768; \quad (PM = 0) \]

**Equation 28**

\[ Ci,v = 8192 \times X_{I,V} / AvI, V - 7168; \quad (PM = 1) \]

where \( X_V \) and \( X_I \) are those calculated in one of the four previous cases.

1.1.5 Coherency check

We can assume that the EM works correctly and that built-in voltage and current sensors allow the target power sensitivity constant to be achieved, because the correction parameters \( K_i \) and \( K_v \) can tune measured values within the calibration range of ±12.5% or ±6.25% if PM = 1 per voltage or current channel.

If, after the calibration, calculated values for \( C_v \) or \( C_i \) are out of their 8 or 10-bit range, it may mean that the application cannot reach the target value of power sensitivity. In this case, steps 3 and 4 must be repeated choosing a smaller power sensitivity value. If the values of \( C_v \) or \( C_i \) are out of range even for small values of PM, it may mean that the energy meter board is not good enough to perform such measurements, possibly because the tolerance of the components is too big, or no care has been taken in the layout phase, so the application must be re-designed.

Otherwise, if the final calibrator data is written into STPMC1, the average RMS readings are very close to target values \( X_I \) and \( X_V \) and the frequency of the LED output are very close to the target value \( f \).
2 Revision history

Table 4. Document revision history

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-Nov-2011</td>
<td>1</td>
<td>First release</td>
</tr>
</tbody>
</table>
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