AN3398
Application note

Fast digital calibration procedure for STPMC1 based energy meters

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.

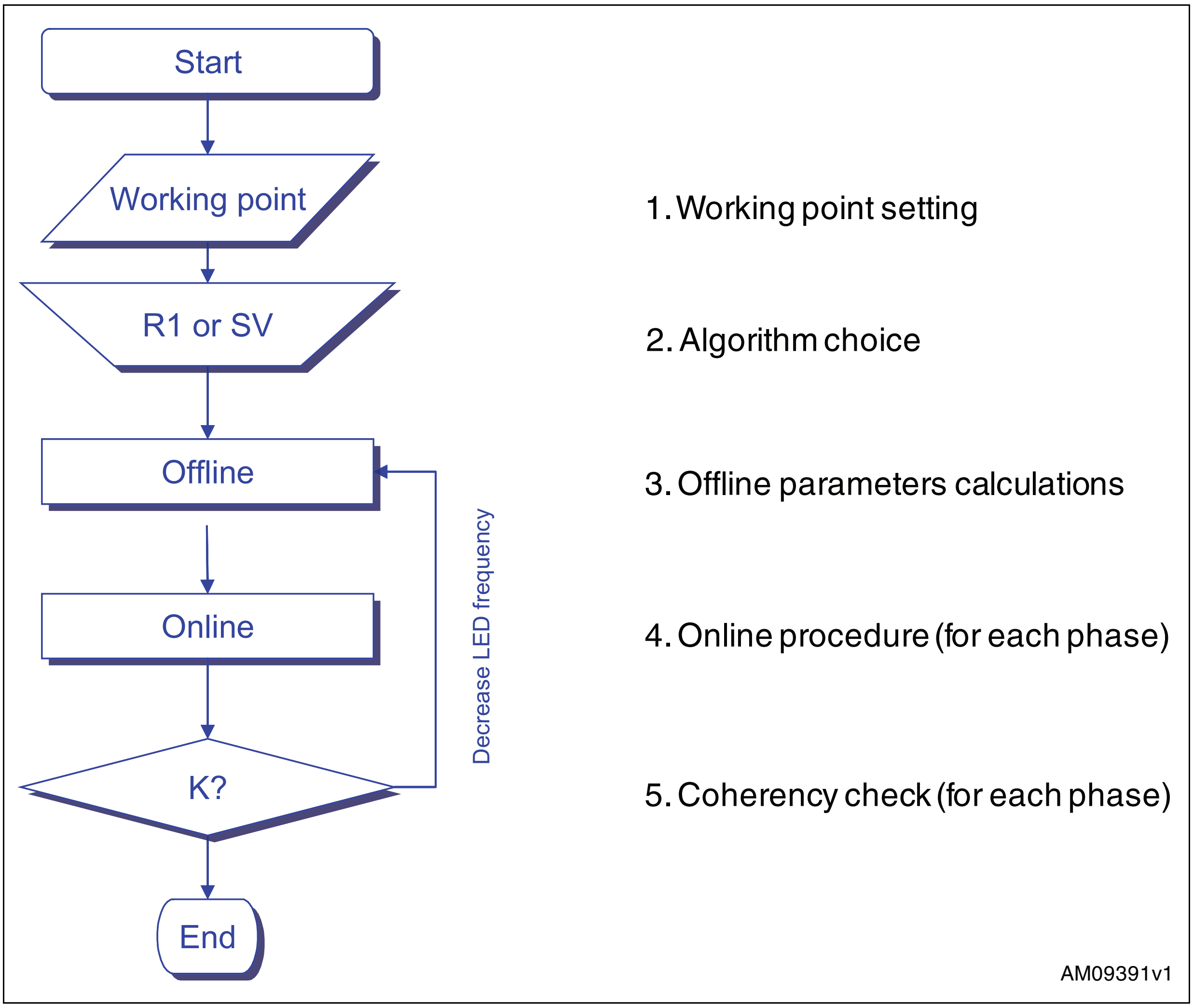
Sections 1, 2, and 3.1 of the AN2299 application note can be considered valid also for the STPMC1 device, sharing the same architecture as STPM01 and STPM10 devices, whilst the calibration calculations shown in section 3.2 of AN2299 and in this document are slightly different and are reported below.

Contents

1 Calibration flow chart

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

Figure 1. Calibration flow chart



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:

Table 1. Working point setting

Parameter	Value	Description
Vn	230 V	Phase to neutral RMS voltage
In	5 A	Phase RMS current

The other parameters, which follow, and the constants of the STPMC1 metering device (and relative tolerances) are also known:

Table 2. STPMC1 internal parameters

Parameter	Value	Description
K_V	0.875	Voltage calibrator ideal value if PM = 0(1)
	0.9375	Voltage calibrator ideal value if PM = 1
K_I	0.875	Current calibrator ideal value if PM = 0
	0.9375	Current calibrator ideal value if PM = 1
len_i	2^16	Current register length
len_u	2^12	Voltage register length
Kint_comp	1.004	Gain of decimation filter
π	3.14159	
FM	4 * 10^6	If oscillator frequency is 4.000 or 8.000 MHz
	2^22	If oscillator frequency is 4.194 or 8.388 MHz
	4915200	If oscillator frequency is 4.915 or 9.830 MHz
D_{UD}	2^17	Internal parameter
Vref	1.23	Internal voltage reference
Au	4	Amplification of voltage ADC for STPMS1
	2	Amplification of voltage ADC for STPMS2
Ai	8	Amplification of current ADC for STPMS1
	32	
	2	Amplification of current ADC for STPMS2
	16	
Kint	0.815	Gain of integrator @ line frequency = 50 Hz
	0.679	Gain of integrator @ line frequency = 60 Hz
Kdif	0.6135	Gain of differentiator @ line frequency = 50 Hz
	0.7359	Gain of differentiator @ line frequency = 60 Hz

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 Av is constant, while Ai 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 ± 12.5% (± 6.25% when PM is set) per voltage or current channel:

Table 3. Calibrator value according to PM

PM	Calibrator value
0	Kv = Ki = 0.875 Ci = Cv = 128
1	Kv = Ki = 0.9375 Ci = Cv = 512

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

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

Equation 2

$$Cv,i = 1024 * Kv,i - 768$$

or when PM = 1

Equation 3

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

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 = (Kv * AvV) / 0.875

Equation 6

X_I = (Ki * AvI) / 0.875

PM = 1:

Equation 7

X_V = (Kv * AvV) / 0.9375

Equation 8

X_I = (Ki * 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 * 64

with:

Equation 10

$f = (C/64 * In * Vn) / 3600000$

Current transformer or Shunt - Constant R_1

In this algorithm voltage divider sensitivity is fixed, therefore, resistor values R_1 and R_2 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

$$V_{DIV} = Vn * R_2 / (R_1 + R_2)$$

Target RMS reading for given Vn:

Equation 12

$$X_V = (V_{DIV} / V_{REF}) * 2 * Kdif * Av * Kv * Kint\_comp * Kint * len\_u$$

Target RMS reading for given In:

Equation 13

$$X_I = f * len\_u * len\_i * D_{UD} / (FM * X_V)$$

From which current sensor sensitivity K_S is obtained:

Equation 14

$$K_S = X_I * V_{REF} * 1000 / (In * Ai * Ki * Kint\_comp * Kint * Kdif * len\_i) \text{ [mV/A]}$$

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

$$X_I = In * K_S * Ai * Ki * Kint * Kint\_comp * Kdif * len\_i / (V_{REF} * 1000)$$

Target RMS reading for given Vn:

Equation 16

$$X_V = f * len\_u * len\_i * D_{UD} / (FM * X_I)$$

Voltage divider output:

Equation 17

$$V_{DIV} = X_V * V_{REF} / (2 * Kdif * Av * Kv * Kint\_comp * Kint * len\_u)$$

From which R1 resistor value is obtained:

Equation 18

$R_1 = R_2 * (Vn - V_{DIV}) / V_{DIV}$ [Ohm]

Rogowski coil - Constant R_1

As before, the voltage divider sensitivity is fixed, therefore, resistor values R_1 and R_2 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

$V_{DIV} = Vn * R_2 / (R_1 + R_2)$

Target RMS reading for given Vn:

Equation 20

$X_V = (V_{DIV} / V_{REF}) * Av * Kv * Kint\_comp * len\_u$

Target RMS reading for given In:

Equation 21

$X_I = f * len\_u * len\_i * D_{UD} / (FM * X_V)$

From which current sensor sensitivity K_S is obtained:

Equation 22

$K_S = X_I * V_{REF} * 1000 / (In * Ai * Ki * Kint\_comp * Kint * len\_i)$ [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

$X_I = In * K_S * Ai * Ki * Kint * Kint\_comp * len\_i / (V_{REF} * 1000)$

Target RMS reading for given Vn:

Equation 24

$X_V = f * len\_u * len\_i * D_{UD} / (FM * X_I)$

Voltage divider output:

Equation 25

$V_{DIV} = X_V * V_{REF} / (Av * Kv * Kint\_comp * len\_u)$

From which R_1 resistor value is obtained:

Equation 26

$R_1 = R_2 * (Vn - V_{DIV}) / V_{DIV}$ [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

$Ci,v = 896 * X_{I,V} / AvI, V - 768; (PM = 0)$

Equation 28

$Ci,v = 8192 * X_{I,V} / AvI, V - 7168; (PM = 1)$

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 Ki and Kv 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 Cv or Ci 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 Cv or Ci 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

Date	Revision	Changes
16-Nov-2011	1	First release