Monitoring of Power Measured by Static Energy Meters for Observing EMI Issues

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***Abstract*—Static energy meters are becoming the standard for measuring the consumed energy in households. Previous research showed that static meters can give faulty energy readings. The blinking light emitting diode (LED) in the meter gives, in many meters, a factor 1000 more accurate reading compared to the display readings. In case possible misreading has to be investigated a series energy meter would be useful, with the additional possibility to readout the blinking LED. This would allow detailed research on the behavior of static energy meters and test possible sources of interference, especially in cases where the energy consumption is low, and the risk of deviation could be high. Such a monitoring system has been designed and implemented allowing to monitor a series of static meters and the consumed energy such that a source of interference can be observed directly.**

Keywords: Static Meter, Smart Meter, Electronic Meter, Interference

I. Introduction

Nowadays, the old fashioned electromechanical energy meters, based on the Ferraris principle, are replaced by static energy meters. These meters are called smart meters if a communication link is added to transmit the recorded data. Some consumers who use these static meters, complain about their meter reading. They claim that the static meter gives higher readings compared to the old electromechanical meter. The electric utilities claim that the customers should be happy that they paid too less for years, because of wear the old meters gave incorrect, and too low readings.

In [1] two neighboring farmers installed the same Photo Voltaic (PV) system, but on sunny days there was a difference of 40% of delivered energy between the two PV systems. Experiments show that high interference levels on the power lines where caused by the power drive systems of the fans. [1], which resulted in faulty readings of the static meter. Faulty readings of static energy meters due to PV systems were also observed in [2], [3]. These where caused due to high interference levels generated by active infeed converters connected to PV systems. In all cases the energy meters gave lower readings.

Research has shown that in some other cases the static meters can give faulty energy readings, positive and negative, if static meters are loaded with pulsed currents [4], [5], [6]. In [4], controlled experiments on static meters show that they can present faulty readings. When using static meters in a three-phase standardized power supply setup, loaded with a string of compact fluorescent lamps (CFL) and light emitting diode (LED) lamps in combination with a dimmer, static meters show a positive deviation of 276% and a negative deviation of -46% compared to conventional electromechanical energy meters. The experimental results in [5] and [6] show that the tested static meters using a standard building power supply gave maximal positive deviations of $+582\%$ and negative deviations of -32% when loaded with CFL and LED lamps in combination with a dimmer for a one-phase test setup. Because the energy consumption of LED and CFL lights is low, these experiments were carried out by measuring over a period of 1 to 2 weeks. All experiments have also been repeated, so the experiments using the standardized power supply took approximately 3 months, and the extended experiments using a mains supply took 4 months to complete. An array of 50 lamps was used such that effects measured by static meters could be observed faster. But this array is not a realistic situation anymore.

Furthermore, for further research on the errors of static energy meters due to interfering sources, it would be beneficial to monitor a series of static meters. Therefore, a test setup was built that can monitor the energy consumption as indicated by around ten static meters in a short period of time. The blinking LED of the static meter is monitored, this gives a 500 to 1000 (depending of the brand of the meter) more accurate reading compared to the LCD display. Monitoring this blinking LED would allow faster experiments.The frequency at which the energy is consumed, the power, is also measured, this is the frequency of the blinking LED. When performing measurements with this setup, interference on the static meters can be observed instantaneously, instead of the 24 hours to 2 weeks as in [4], [5] and [6].

The rest of the paper is organized as follows. Section II describes the static meter setup that is used. In section III the monitoring of the energy consumption as measured by the static meter is described. Section IV describes the data processing needed for the test setup to process the energy consumption into the real power transferred over a certain period. Section V describes a simple verification of the test setup using a linear load. Section VI describes some disturbances of the setup due to injection of radio frequency signals. And finally Section VII gives the concluding remarks of the study.

II. Static meter setup

A series of 10 static meters are connected in series using one-phase, because some of the meters are single-phase types. Fig. 1 and Fig. 2 show the static meter test setup. Meters that are included in the test setup have different types of current sensors: shunt resistor, current transformer, Hall effect-based current sensor and Rogowski coil. The meters are representative of the installed base of energy meters in The Netherlands. The meters are fed using standard mains supply, but it is also possible to feed them using a generator to create a clean supply with a standardized mains impedance.

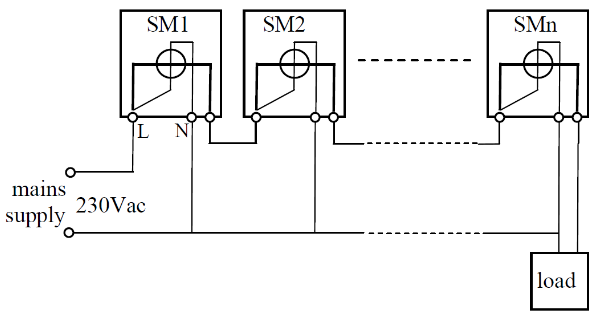

Fig. 1. Schematic of the static meter test setup

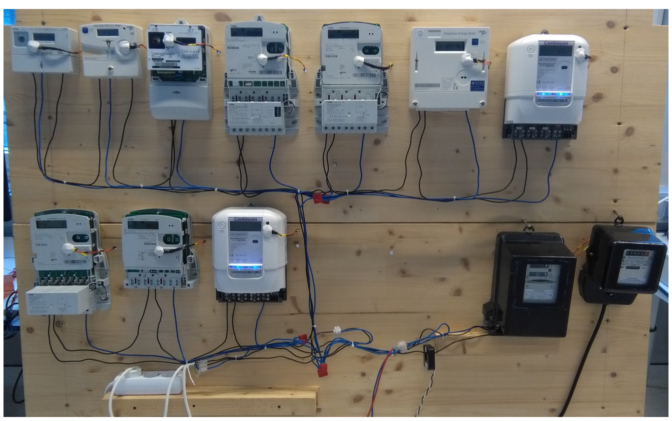

Fig. 2. Picture of the static meter test setup

In the test setup, the static meters are placed in series with each other which means that SM1 also measures the energy which is consumed by SM2 to SMn. Therefore, the energy meter reading is corrected with the consumed energy of the following meters.

III. Monitoring energy consumption

The static meters have a blinking LED integrated, which blinks if a certain amount of energy is consumed. For most of the meters this is one blink per 1 or 2 Wh of energy consumed in the circuit. This LED pulse can be monitored by attaching it to an optical sensor. Such an optical sensor should give a voltage dependent on whether the LED is on or off, such that this blinking LED can be translated into an analog voltage signal. A light dependent resistor (LDR) for which the resistance is inversely proportional to the intensity of the light it receives, can be used for this purpose. Using the LDR and a $1\,\mathrm{k\Omega}$ resistor, a voltage divider is created, such that the output voltage over the resistor can be measured. This voltage divider is fed with an input voltage of $5\,\mathrm{VDC}$ and the output is connected to an Arduino Mega microcontroller. When the LDR is connected to a static meter, loaded with a resistive load of $850\,\mathrm{W}$, meaning around 14 LED blinks per minute, the output can be seen in Fig. 3. When the LED is turned off, the output is almost zero and when the LED is on a clear voltage pulse can be seen. This configuration can translate the blinking LED into a voltage signal correctly.

However, the response time is moderate, the falling edge of the pulse is rather slow and is creating a wide pulse. Furthermore, it needs more than one data point to get to its maximum value, as can be seen in Fig 4. This can become problematic if there are a lot of pulses close to each other. Therefore, another configuration is made using so called light-to-voltage optical sensors, which is an IC packet combining a photodiode and a transimpedance amplifier. Photodiodes have a quicker response time compared to a LDR and should therefore solve this problem. The output voltage of this sensor is directly proportional with the light intensity directed on the photodiode. A TSL261RD light-to-voltage optical sensor is used, the photodiode spectral responsivity shows that it is sensitive to wavelengths around $900\,\mathrm{nm}$. Again, the output of the sensor is connected to an Arduino Mega microcontroller. Fig. 3 shows the output of the sensor when the static meter is connected to a resistive load of $850\,\mathrm{W}$. Fig. 4 shows a zoomed version of the response. It can be seen that the response time is much quicker and as a result the pulse looks much smoother compared to the LDR.

A drawback of using this specific light-to-voltage optical sensor is that the intensity and the wavelength of the LEDs is not exactly the same for the different static meters. Therefore, using this sensor, it was not possible to measure all of the static meters included in the test setup. Another light-to-voltage optical sensor was used, the TSL257. This photodiode is sensitive to wavelengths between 500 and $800\,\mathrm{nm}$. The result of using this optical sensor can also be seen in Fig. 3, it shows that the pulse is very smooth. When the LED is turned off, this sensor shows a much higher voltage compared to the other two sensors, because it is not only sensitive to the blinking LED, but also to the ambient light. However, when the sensor is interfered with ambient light, it does not give a noisy signal.

A combination of these three optical sensors is attached to the static meters test setup. The sensors are attached to the static meters using some sticky material, and can be seen in Fig. 5.

IV. Data processing

In order to process the data and count the number of pulses created by the optical sensors, these sensors are connected to an Arduino Mega microcontroller. To verify when there is a pulse, the output voltage of the optical sensors should

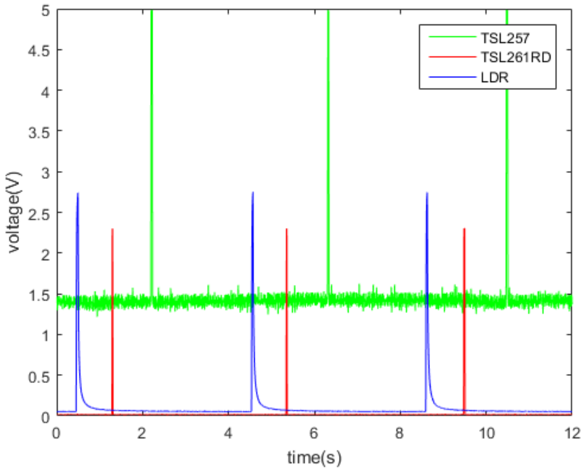

Fig. 3. Response of the optical sensors connected to a LED on a static meter when loaded with 850 W resistor. For optical sensors: TSL257 in green, TSL261RD in red and LDR in blue.

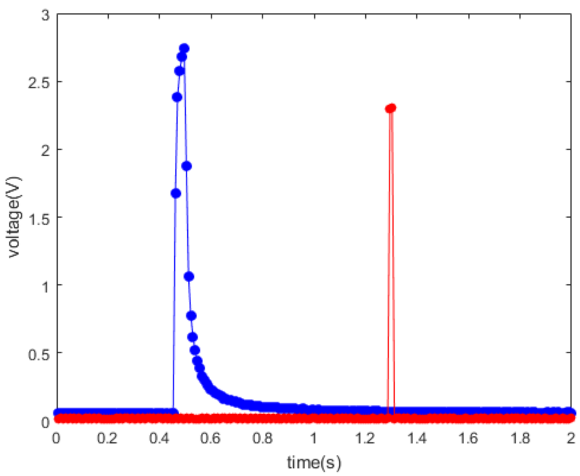

Fig. 4. Zoomed version of the response of the optical sensors connected to a LED on a static meter when loaded with 850 W resistor, dots indicate the data points. For optical sensors: TSL261RD in red and LDR in blue.

exceed a certain threshold voltage. These threshold voltages are determined experimental for each individual optical sensor.

The microcontroller reads all of the 10 optical sensors continuously and compares these voltages to the threshold level. Since two situations are possible, either a pulse or no pulse, this is programmed as a state machine with two states. In $\mathrm{curState} = 0$ there is no pulse and in $\mathrm{curState} = 1$ there is a pulse. It goes from state 0 to 1 if the voltage rises the threshold and from 1 to 0 if the voltage falls under this threshold. The pulse counter is incremented at the moment that the state changes from 0 to 1. A state diagram is shown in Fig. 6. This procedure is performed for every optical sensor, such that the output data is an array of elements containing the amount of measured pulses for each individual static meter.

After a certain time interval, this data is written to the serial monitor of the microcontroller, which is attached to a computer running MATLAB to process the data. The interval in which the data is updated to the serial monitor can change dependent on the measurements, normally around 30 to 60 seconds. This data consists of the number of pulses for each static meter and a timer indicating the total length of the measurements.

Fig. 5. Optical sensors as attached to a static meter

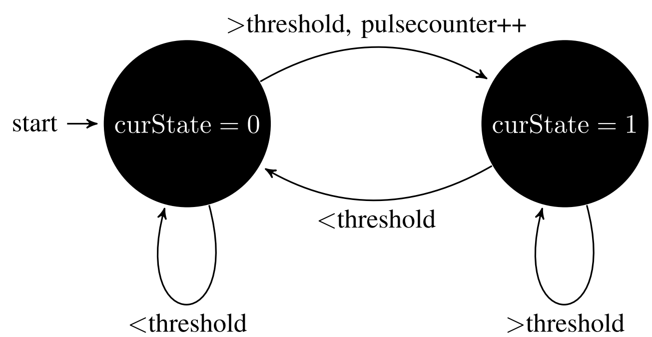

Fig. 6. State diagram of the microcontroller

Using the number of pulses and the elapsed time, the frequency at which the pulses occur can be determined. The frequency at which the pulses occur is the energy per amount of time, which is the real power transferred in the circuit, eq. 1. Where P is the real power transfered, E is the energy consumed and t is the time. This real power can be calculated over the whole measurement period or over the data from the last update of the microcontroller only.

$$\mathrm{P}\,[\mathrm{W}] = \frac{\mathrm{E}\,[\mathrm{Wh}]}{\mathrm{t}\,[\mathrm{h}]} \tag{1}$$

For this setup, it is of great benefit that it can be seen directly if a possible source of interference interferes with the test setup. This can be achieved by calculating the real power transferred over the last update of the microcontroller. The data obtained from the microcontroller is the total time and total number of pulses. The number of pulses counted is translated to energy consumed, by using the LED pulse speed of the static meter, which is the number of pulses the LED has per kWh consumed, as can be seen in eq. 2. The data of the last update is also stored in MATLAB and compared to the new data to get the real power over the last update, as can be seen in eq. 3.

$$\mathrm{energy_i}\,[\mathrm{Wh}] = \mathrm{pulses_i} \cdot \mathrm{LEDpulseSpeed_i} \tag{2}$$

$$\begin{aligned} &\Delta\,\mathrm{energy}\,[\mathrm{Wh}] = \mathrm{energy_{upd}}\,[\mathrm{Wh}] - \mathrm{energy_{old}}\,[\mathrm{Wh}] \\ &\Delta\,\mathrm{time}\,[\mathrm{s}] = \mathrm{time_{upd}}\,[\mathrm{s}] - \mathrm{time_{old}}\,[\mathrm{s}] \\ &\mathrm{real\,power}\,[\mathrm{W}] = \frac{\Delta\,\mathrm{energy}\,[\mathrm{Wh}]}{\Delta\,\mathrm{time}\,[\mathrm{s}]} \cdot 3600 \end{aligned} \tag{3}$$

Using this procedure, every time there is new data present at the serial monitor, the real power transferred over this interval as measured by the static meters is calculated.

V. Verification Setup

This section shows a verification of the test setup that is built as described in the previous chapters.

A. *LED pulse counting*

To verify if this setup can monitor the static meters correctly, a resistive load of 1900 W is connected to the setup and the energy consumption monitored by our setup to the energy consumption as indicated on the screens of the static meters is compared. The measurement took around 21 hours and seven meters where monitored during this period. Table I shows the results of this verification, which shows that the difference between the LED pulse counting and the values as indicated on the screens of the static meters is within 3%. Most of the static meters indicate the energy consumed in kWh on their screen (this is true for: SM2, SM3, SM4, SM6 and SM7), while the pulse counter measures in the order of Wh consumed. This causes differences above 1%, for the rest of the static meters the difference is much closer. So it can be said that the setup is able to count the LED pulses correctly, with a small measurement error.

TABLE I
Comparison between energy consumption measured and indicated on the screens of the static meters.

SM	Measured [Wh]	Screen SM [Wh]	Difference [%]
SM1	40085	40300	-0.53
SM2	40014	41000	-2.40
SM3	39988	40000	-0.03
SM4	39946	41000	-2.57
SM5	39731	39970	-0.60
SM6	39335	40000	-1.66
SM7	39780	40000	-0.55

B. *Power measurement*

A simple test has been done to show that the measurement setup can detect changes in power transferred in the circuit fast, as would be the case when an interfering source is turned on or off. For this test a static meter is loaded with a resistor of 1900 W. When the measurements start, the resistor is turned off and consumes no energy, and it is turned on and off again after some time. It is expected that these two situations are clearly visible in a short time period.

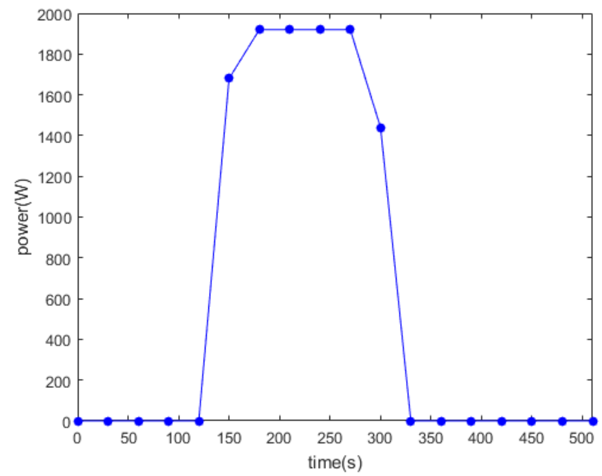

Fig. 7. Power response of a static meter, when a resistive load is turned on and off.

Fig. 7 shows the result of this test, the data is obtained from the microcontroller every 30 seconds. When the resistive load is turned on, then within a minute the setup shows that the static meter is loaded with approximately 1900 W. Only one static meter is shown in the figure, because all other meters tested show the same behavior.

VI. Disturbance in EMI experiments

EMI experiments are performed on the injection of radio frequency (RF) signals, between 10 and 110 MHz, to the circuit using a current injection clamp. These experiments are performed in a Faraday cage to make sure that the setup is not disturbed by the surrounding and vice versa. The injection of current is done using the MIL-STD-461F CS114 test setup [7].

When performing these experiments, it was found that the injected signal was also coupled into the wires between the sensor and the microcontroller. This interference was reduced using a couple of ferrite clamp-on cores, which are wrapped around the wires one or more times. Fig. 8 shows these ferrite clamp-on cores as attached to the wires between the sensor and microcontroller. Using the ferrite cores the interference on the wires was attenuated, such that a decent measurement result was obtained.

VII. Conclusion

To perform research on the actual causes of errors on static energy meters due to interfering sources, a setup is made, which can be used to monitor a couple of static meters very fast. The setup is capable of showing the real power transferred in a circuit over a short time interval of around 30 seconds. This will allow to pinpoint possible sources of electromagnetic interference.

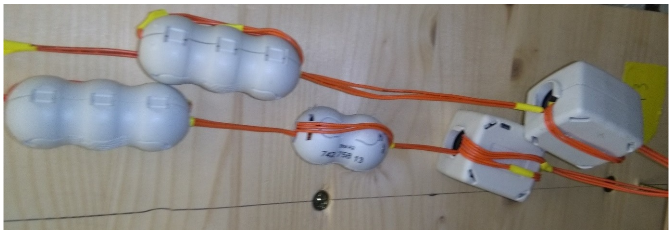

Fig. 8. Ferrite clamp-on cores wrapped around the wires between the sensor and microcontroller.

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