



# Faulty Readings of Static Energy Meters Caused by Conducted Electromagnetic Interference from a Water Pump

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**Abstract.** Conducted electromagnetic interference (EMI) can affect the energy readings of static energy meters. Lower readings of static energy meters have been reported in many publications, and higher readings were found when lighting equipment in combination with a dimmer was used as a load. In this paper it is shown that by using an off the shelf water pump as a consumer, faulty deviations on the static meters with respect to a reference meter can be found. In the most extreme case, using a standard mains supply, deviations between -61% and +2675% were found. When an ideal power supply with a standardized mains impedance was used deviations between -19% and +483% were shown to exist.

## Key words

Static Meter, Smart Meter, Electronic Meter, Conducted Interference, Electromagnetic Compatibility

## 1. Introduction

A main cause of EMI is conducted interference, where several conducted EMI cases have been described in [1]. Conducted interference is nowadays created by cyclic switching of non-linear electronic devices [2]. In [2], a case is described where two neighboring farmers installed the same photo voltaic (PV) system, but on sunny days a +40% difference of power generated between the farmers was observed. Experiments showed that high interference levels on the power lines were caused by the power drive systems of the fans. This resulted in faulty readings of the installed static electricity meter. In [3], [4], lower readings of static energy meters were observed. These were caused due to high interference levels generated by active infeed converters connected to PV systems. In other cases it was also shown that it was possible to get faulty energy readings if static meters are loaded with pulsed currents [5], [6], [7]. For which [5] presents controlled experiments on static meters that show that they can present faulty readings. When a series of static meters are powered with an ideal sinusoidal power and loaded with a dimmer and a series of compact fluorescent lightning (CFL) and light emitting diode (LED) lamps, the experiments show positive deviations of +276% and negative deviations of -46%, compared to a conventional electromechanical

energy meter. When a standard mains power supply was used, deviations between +582% and -32% were found [6], [7]. Static electricity meters are currently widely deployed by utilities across Europe. The purpose of a static electricity meter is to measure the energy consumption in a household situation [8], [9]. When it is combined with communication capabilities it is called a smart meter. The objective of smart meters is to make use of the (price) dynamics in future smart grids.

Since the publication of [5], [6], [7], many possible interference cases have been reported. Some of them have shown unexpected energy consumption, but not explicitly due to faulty readings of static meters. However, faulty energy readings have also been observed, such as an off the shelf water pump used by a consumer. The consumer observed higher energy readings of his static meter when using the water pump. This water pump, suitable for Koi and fish ponds, has a remote unit to control the pumps capacity. The remote control can vary the capacity in ten levels between 8000 and 15000 liter per hour. The power consumption related to these levels is between 23 and 130 Watt, respectively, specified by the manufacturer. By using this remote control with the pump, small pulsed currents will occur. The consumer complained about high energy meter readings, and experiments at the customer's premises showed a large deviation of the installed smart meter compared to the reference meter. In this paper, lab experiments will be described, where this pump in combination with the remote control is used as a load for a series of static meters. To power the setup two different approaches will be used: first, measurements will be done with a standard mains supply and secondly the measurements will be repeated with an ideal sinusoidal waveform, for which three different configurations are used concerning the impedance of the network, making it a standardized mains, low or high impedance network. The purpose of this paper is to monitor the power consumption as indicated by the static meters and confirm if this will give deviations in the static meter readings with respect to a reference meter.

The rest of the paper is organized as follows: Section II describes the measurement setup that was used, Section III shows the results of the measurements, in Section IV the

measurement results are discussed and in Section V some concluding remarks are made.

## 2. Measurement setup

This section describes the measurement setup that is used for performing the measurements. For the measurements two different power sources are used: a standard mains supply and an ideal power supply network, via a 4-quadrant amplifier. The power generated by the source is supplied to a series of ten static energy meters, which can be seen in Fig. 1. The 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 represent the installed base of energy meters in the Netherlands. The energy meter readings of the static meters is corrected with the consumed energy of its following static meters. A water pump is used as a load and is placed inside a circular container, which is filled with water, as can be seen in Fig. 2. The power consumption, as measured by the static meters, is monitored using the method described in [10]. A Yokogawa WT500 power analyzer is used as reference meter for the series of static meters. It has a basic power accuracy of 0.1% and a high sampling rate and experience has shown that we trust the readings for reference as we are focused on EMI, and not on metrology. The accuracy of the meters is not evaluated, but the EMI effects are investigated. The reference meter is placed between the static meters and the load. Fig. 3 shows a schematic overview of the complete measurement setup. The current and voltage at the input of the static meter setup is measured during the measurements using a Tektronix current probe, a Textronix AM503 probe amplifier and a Keysight N2843A voltage probe.

### A. The mains power supply of the building

For the measurements with a standard mains supply the power is drawn directly from the power socket in the lab. This way the setup is supplied with a 50 Hz sinusoidal voltage of 230 V<sub>RMS</sub>. This sinusoidal voltage is not a complete ideal sine-wave, but is distorted by the mains.

### B. Ideal power supply

For these measurements, an ideal, non-distorted, single phase sinusoidal voltage is generated using a Pacific Power Smart Source 140-TMX AC power source, which is a 4-quadrant amplifier. This is done such that the static meters and load are not disturbed by the non-ideal behavior of the supply created by a standard mains.

For this ideal power supply three different cases for the impedance of the network are implemented:

- 1) *Standardized mains network*: using a line impedance stabilization network (LISN) to provide a stable impedance to the power input of the static meters and the load for the higher frequencies, for the lower frequencies the internal impedance of the Pacific Power fulfills the IEC 61000-4-11 standard [11].



Fig. 1. Picture of the ten static meters placed in series, the energy meter reading of the static meters is corrected with the consumed energy of the following static meters



Fig. 2. Picture of the water pump placed inside a circular container filled with water

- 2) *Low impedance network*: using a 28.2  $\mu\text{F}$  capacitor between phase and neutral.
- 3) *High impedance network*: using a 1.4 mH inductor in series.

## 3. Results

In this section the results of the measurements will be described. First, the results using a standard mains supply are presented. Secondly, the measurement results using the ideal power supply are shown, which is subdivided into: a standardized mains, low and high impedance network. The current waveforms associated with the corresponding water pump capacity levels for the ideal power supply with a standardized mains impedance network can be seen in Fig. 4.

### A. The mains power supply of the building

The first measurements are performed using the mains power supply of the building. The measurement results

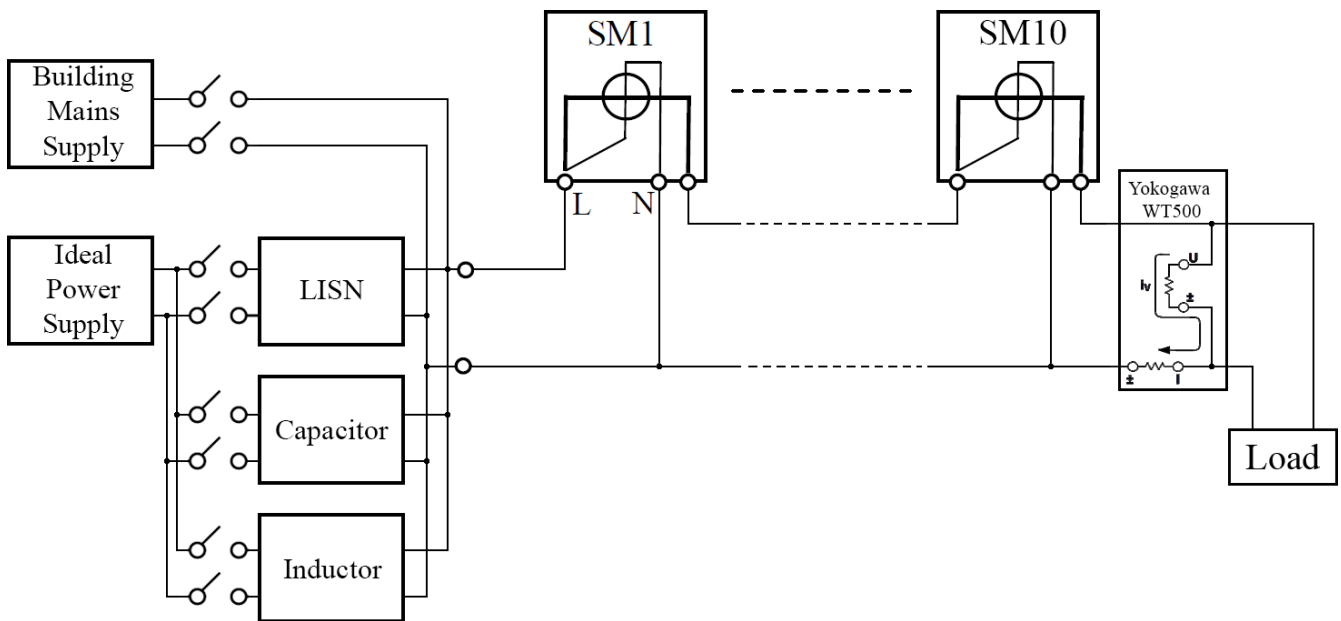


Fig. 3. Schematic overview of the measurement setup, ten static meters (SM) are connected

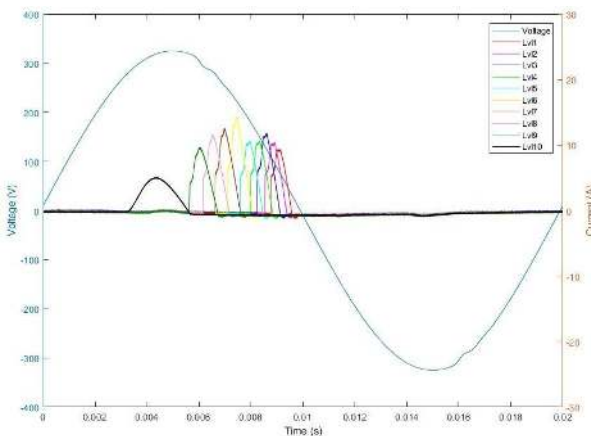


Fig. 4. Measured current waveforms for the ten different levels of the water pumps capacity, between the ideal power supply with a standardized mains impedance and the static meters with respect to the voltage waveform

can be found in Fig. 5, which shows the deviations of the static meters with respect to the reference meter, per level of the water pump's capacity. Using the mains power supply of the building deviations between -61% and +2675% are found.

#### B. Ideal power supply

These measurements are performed with an ideal power supply generated by the 4-quadrant amplifier, to get reproducible results in the most ideal case. Results with three different impedance configurations have been tested.

- 1) *Standardized mains impedance*: In the most ideal case a non-distorted sine-wave is supplied and the impedance of the network is standardized. Using this configuration the static meters show some deviations with respect to the reference, as can be seen in Fig. 6. This figure shows the deviations of the static meters with respect to the reference meter, per level of the water pump's capacity,

where deviations between -19% and +483% are found.

- 2) *Low impedance*: The measurements are repeated and the impedance of the network is changed to a low impedance network. Fig. 7 shows the results using this configuration, where deviations between -17% and +2114% are found and are plotted in the same configuration as before.
- 3) *High impedance*: The measurements are repeated again, but this time a high impedance network is used. Fig. 8 shows the results using this configuration, where deviations between -16% and +316% are found for different static meters with respect to the reference meter, per level of the water pump's capacity.

## 4. Discussion

Many experiments were performed with a water pump as a load for the static meters and several deviations of the static meters were found. If the water pump is set to a lower capacity level, using the remote control, less power is consumed by the water pump. At this lower capacity level, the current waveform has a higher phase shift, see Fig. 4. In the measurements higher deviations of the static meters are observed at a lower capacity level, Fig. 5-8. For all the measurements conducted, higher deviations of the static meters occur when the current has a higher phase shift.

When using an ideal power supply, changing the impedance from a standardized mains to a low impedance network results in much higher deviations, as the maximum deviations changes from +483% to +2114%, see Fig. 6 and 7. This can be explained, because the capacitive behavior of the system allows the high-frequency currents drawn by the load to flow easy, increasing the detrimental effect even further. When using a high impedance network much smaller deviations in energy meter readings were found compared to the

standardized mains impedance network, which can be seen when comparing Fig. 6 and 8.

The results using a standard mains supply show higher deviations compared to all the cases using an ideal power supply, Fig. 5-8. This shows that in household situations even higher deviations can occur than in controlled lab experiments.

## 5. Conclusion

It was already known that it is possible to have high deviations in energy consumption between static meters. The results found in this paper show that by using an off the shelf water pump it is also possible to get faulty readings of static meters. The water pump was in use by a consumer who complained about the high energy bill. Therefore, experiments in the lab have been performed. Using an ideal power supply with a standardized mains impedance, deviations between -19% and +483% are found. When the impedance is changed to a low impedance network, higher deviations between -17% and +2114% are found. A high impedance network shows lower results compared to the standardized mains impedance network, where the deviations are between -16% and +316%. When the mains power supply of the building is used even higher results are found, which are between -56% and +2675%. Higher deviations occur if the current has a higher phase shift.

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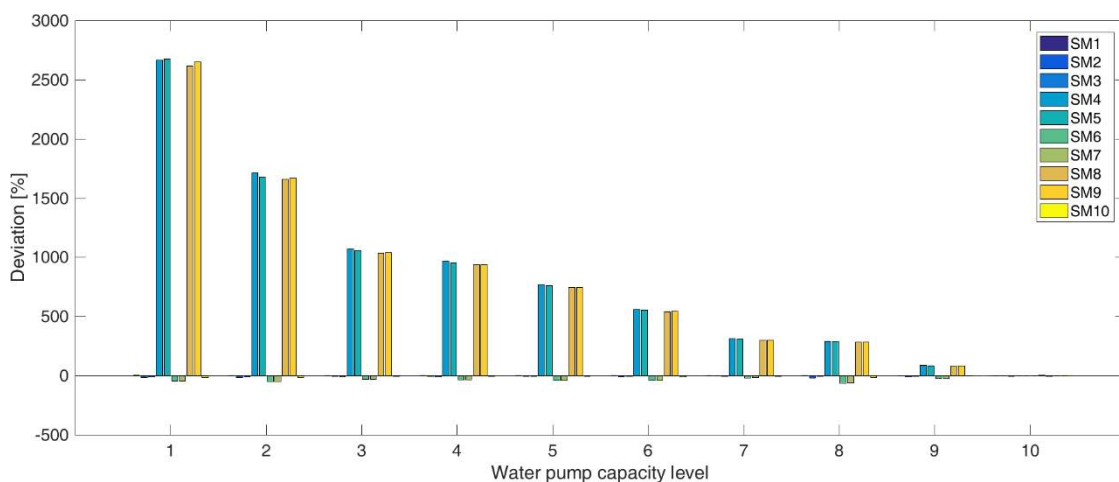


Fig. 5. Visual representation of the deviations [%] between the static meters (SM) and reference when the setup is powered using the mains power supply of the building, for the ten different levels of the water pumps capacity

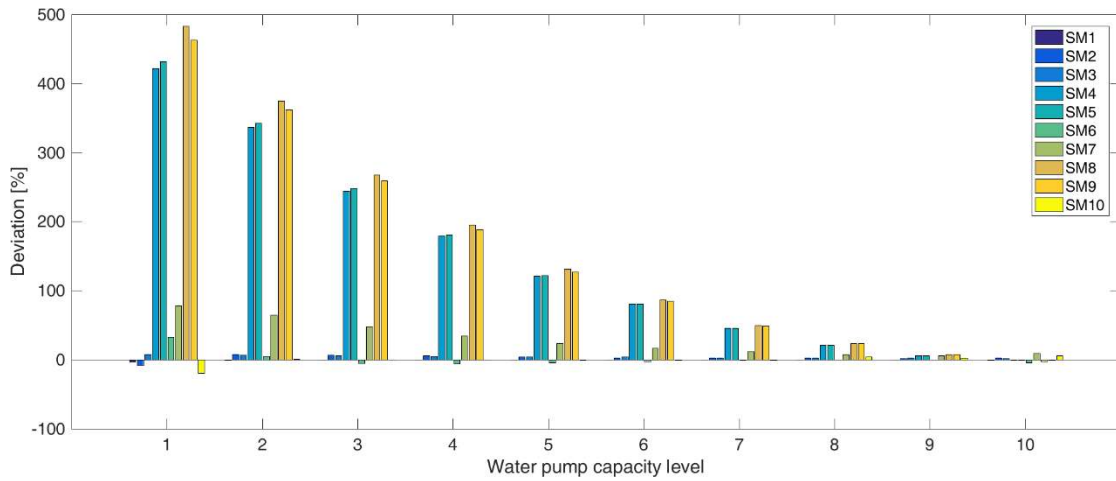


Fig. 6. Visual representation of the deviations [%] between the static meters (SM) and reference when the setup is powered using the ideal power supply with a standardized mains impedance, for the ten different levels of the water pumps capacity

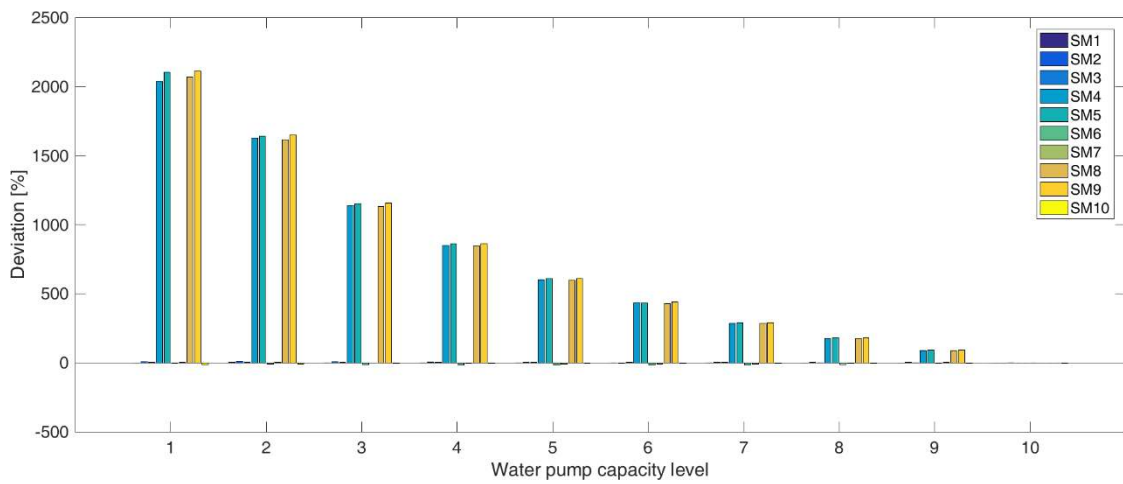


Fig. 7. Visual representation of the deviations [%] between the static meters (SM) and reference when the setup is powered using the ideal power supply with a low impedance, for the ten different levels of the water pumps capacity

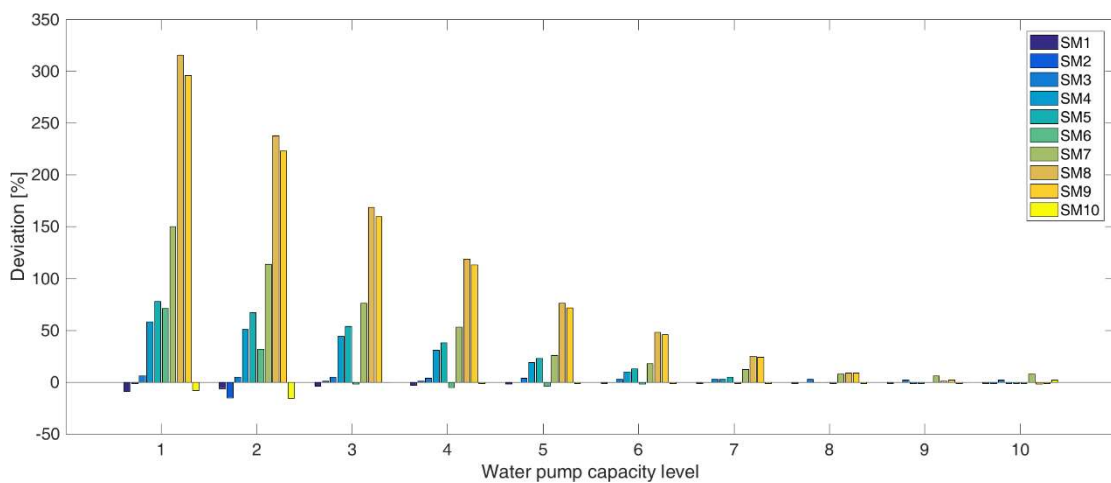


Fig. 8. Visual representation of the deviations [%] between the static meters (SM) and reference when the setup is powered using the ideal power supply with a high impedance, for the ten different levels of the water pumps capacity