

ELECTRICITY METER WITH SERVICE DISCONNECT SWITCH**TECHNICAL FIELD**

5 The present disclosure is in the field of electricity meters for metering of electricity consumption, such as in residential and commercial premises. The disclosure relates, in particular, to electricity meters having a service disconnect switch.

BACKGROUND

10 An electricity meter, also known in the art as an electrical power meter, electric meter or electrical meter, is a device that measures an amount of electrical power consumed by one or more electrically powered devices over a time interval, such as at a residential or commercial premises.

15 Electricity meters are typically installed at premises for purposes of billing and monitoring of consumption. In some examples, electricity meters may be manually, periodically read to determine a level of electrical power consumption. In other examples, advanced electricity meters known in the art as 'smart meters' may be configured to communicate with a utility provider, e.g. wirelessly, to provide electrical power
20 consumption information and/or receive billing information and/or control signals.

 Electricity, e.g. electrical power, may be delivered to a premises by a range of available service types, such as: single phase three wire commonly used in residential premises the United States; three phase four wire Wye commonly used in commercial premises in the United States; and three phase three wire delta commonly used in
25 industrial facilities in the United States. Different service types have associated electricity meter forms, e.g. 2S, 3S, 5S, etc., as is well known in the art, and as described below in further detail.

 One technique for automated or remote electricity service disconnection is to employ a service disconnect switch device within an electricity meter. The
30 service disconnect switch is a relay or other switching device between a load-side and a grid-side of the electricity meter, for selectively disconnecting a power supply at the grid-side from a load at the load-side.

 The load-side of an electricity meter may refer to a connection of the electricity meter to an electrical power consuming load. The grid-side of an electricity meter may

refer to a connection of the electricity meter to a power supply line from a utility provider, e.g. from the electrical grid.

In some cases, the service disconnect switch is tripped by a remote device that communicates with the electricity meter circuitry through a modem, radio or the like.

5 Alternatively, such as in the case of prepayment, the meter itself may be programmed to disconnect and reconnect electrical service under certain circumstances. In some situations, the meter may disconnect and restore electrical service through a combination of local programming and remote commands.

10 SUMMARY

For reducing wear and tear of switch contacts of the service disconnect switches, it desirable to make or break mechanical contacts of the switch contacts when the electrical power, e.g. AC electrical power like the AC electrical voltage and/or the AC
15 electrical current, to be switched is not at a peak, such that a formation of arcs is at least reduced or even prevented. The randomness of the service disconnect operation results in a flat distribution of the probability that the switch will operate and the likelihood and severity of arcing that can transpire during the actuation. The arcing causes wear on the contacts of the service disconnect switch.

20 Known electricity meters use a service disconnect switch having at least two contacts per phase to provide redundancy due to the wear. The inventors have identified that having these multiple contacts increases complexity of the assembly of the electricity meter and increases the size of the electricity meter.

According to one aspect of the present disclosure there is provided an electricity
25 meter comprising: a grid-side input terminal and a load-side output terminal; a switch coupled between the grid-side input terminal and the load-side output terminal; an actuator coupled to the switch, the actuator configured to output a switching signal to the switch to change a switching state of the switch; and a processor arranged to output a control signal to the actuator to cause the output of the switching signal; wherein the
30 processor is configured to: determine, at a determination time, that the switching state of the switch is to be changed; use a switch characterization tool, to determine an estimated switching time period between (i) output of a control signal from the processor to the actuator and (ii) a change of the switching state of the switch; monitor a waveform of the electricity meter; determine from the waveform and the
35 estimated switching time period, an output time at which to output the control signal such

that the switching state of the switch will change when the waveform reaches a target point; output the control signal to the actuator at the output time, to cause the output of the switching signal from the actuator to the switch; monitor at least one load-side waveform of the electricity meter on a connection between the switch and the load-side output terminal to detect an actual switching time period between (i) the output of the control signal and (ii) a change of the switching state of the switch; and modify the switch characterization tool based on the actual switching time period.

In embodiments of the present disclosure, the processor monitors and then characterizes the operation of the actuator over time, and then adjusts the timing of the output of the control signal used to change the switching state of the switch, to ensure that the switching state of the switch will change when the waveform reaches a target point. The target point can be a point which will reduce or eliminate the contact wear for a properly timed operation (i.e. will reduce the amount or severity of the arcing observed during the switch operation). For example, embodiments of the present disclosure can advantageously avoid the switching state of the switch changing when the AC electrical power, like the AC electrical voltage and/or the AC electrical current, is at its peak and instead ensure that the switching state of the switch changes at, or close to, a zero crossing of the waveform.

The reduction in wear means that it is possible to reduce the thickness of the contacts in each service disconnect switch, or eliminate completely one or more of the service disconnect switch contacts used in known electricity meters (because it is not necessary to have the redundancy of having multiple contacts in each service disconnect switch). This advantageously results in reduced complexity of the assembly of the electricity meter and decreases the size of the electricity meter.

Known methods to account for the arcing referred to above include using a material (e.g. a silver cadmium alloy) on the contacts of the service disconnect switch in order for the service disconnect switch to survive the damage caused by the arcing incurred over the required life of the switch. By controlling the switch to change switching state when the waveform reaches the target point, the damage to the service disconnect switch is reduced allowing for a reduction (or elimination) of this material, or a change to a different material.

The waveform of the electricity meter may be a grid-side waveform present on a connection between the grid-side input terminal and the switch.

The processor may be configured to monitor the grid-side waveform of the electricity meter whilst the switch is in a closed state. The grid-side waveform may be a grid-side voltage waveform or a grid-side current waveform.

5 The grid-side waveform may be a grid-side voltage, and the processor may be configured to monitor the grid-side waveform of the electricity meter whilst the switch is in an open state.

The waveform of the electricity meter may be a load-side waveform present on the connection between the switch and the load-side output terminal. The load-side waveform may be a load-side voltage waveform or a load-side current waveform.

10 The at least one load-side waveform of the electricity meter may comprise one or both of a load-side voltage waveform and a load-side current waveform.

The actuator may comprise an electric motor. The electric motor is advantageously more reliable and less prone to tamper than other technologies (like relays and solenoids).

15 The actuator may comprise a solenoid and/or a relay. A solenoid and a relay advantageously has a more repeatable operation than a motor but there is still a delay associated with these circuits since they are electromechanical.

The processor may be configured to use a temperature associated with the switch at said determination time, to determine the estimated switching time period.

20 The processor may be configured to use an age of the switch to determine the estimated switching time period.

The processor may be configured to use a number of switch actuations performed by the switch to determine the estimated switching time period.

25 In some embodiments the switch characterization tool is a look-up table. In other embodiments the switch characterization tool is an equation. In other embodiments the switch characterization tool is a machine learning model.

The target point may be a zero crossing of the waveform.

30 According to another aspect of the present disclosure there is provided a method of operating an electricity meter, the method comprising: determining, at a determination time, that a switching state of a switch of the electricity meter is to be changed, the switch coupled between a grid-side input terminal and a load-side output terminal of the electricity meter; using a switch characterization tool, to determine an estimated switching time period between (i) output of a control signal to an actuator coupled to the switch and (ii) a change of the switching state of the switch; monitoring a waveform of
35 the electricity meter; determining from the waveform and the estimated switching time

period, an output time at which to output the control signal such that the switching state of the switch will change when the waveform reaches a target point; outputting the control signal to the actuator at the output time, to cause the output of a switching signal from the actuator to the switch; monitoring at least one load-side waveform of the electricity meter on a connection between the switch and the load-side output terminal to detect an actual switching time period between (i) the output of the control signal and (ii) a change of the switching state of the switch; and modifying the switch characterization tool based on the actual switching time period.

According to another aspect of the present disclosure there is provided a non-transitory computer-readable storage medium comprising instructions for operating an electricity meter, the instructions when executed by a processor of the electricity meter cause the processor to: determine, at a determination time, that a switching state of a switch of the electricity meter is to be changed, the switch coupled between a grid-side input terminal and a load-side output terminal of the electricity meter; use a switch characterization tool, to determine an estimated switching time period between (i) output of a control signal to an actuator coupled to the switch and (ii) a change of the switching state of the switch; monitor a waveform of the electricity meter; determine from the waveform and the estimated switching time period, an output time at which to output the control signal such that the switching state of the switch will change when the waveform reaches a target point; output the control signal to the actuator at the output time, to cause the output of a switching signal from the actuator to the switch; monitor at least one load-side waveform of the electricity meter on a connection between the switch and the load-side output terminal to detect an actual switching time period between (i) the output of the control signal and (ii) a change of the switching state of the switch; and modify the switch characterization tool based on the actual switching time period.

The instructions may be provided on one or more carriers. For example there may be one or more non-transient memories, e.g. a random-access memory (RAM), read-only memory (ROM), an optical disc, flash memory, hard disk memory, and other memory devices that may use magnetic, optical, and other techniques to store instructions and other data. The memory/memories may be integrated into a corresponding processing chip and/or separate to the chip. Code (and/or data) to implement embodiments of the present disclosure may comprise source, object or executable code in a conventional programming language (interpreted or compiled) such as C, or assembly code, code for setting up or controlling an ASIC (Application Specific

Integrated Circuit) or FPGA (Field Programmable Gate Array), or code for a hardware description language.

The above summary is intended to be merely exemplary and non-limiting. The disclosure includes one or more corresponding aspects, embodiments or features in isolation or in various combinations whether or not specifically stated (including claimed) in that combination or in isolation. It should be understood that features defined above in accordance with any aspect of the present disclosure or below relating to any specific embodiment of the disclosure may be utilized, either alone or in combination with any other defined feature, in any other aspect or embodiment or to form a further aspect or embodiment of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the present disclosure will now be described, by way of example only, with reference to the accompanying drawings, wherein:

- Figure 1** depicts a block diagram of a prior art electricity meter in series with a load, the electricity meter having the 2S form;
- Figure 2** depicts a further example of a prior art electricity meter;
- Figure 3** depicts a plurality of contacts used in a service disconnect switch;
- Figure 4** depicts an electricity meter, according to an embodiment of the disclosure;
- Figure 5** depicts a flowchart of a method of generating a switch characterization tool; and
- Figure 6** depicts a flowchart of a method of using and modifying a switch characterization tool.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 depicts a block diagram of a prior art electricity meter 100. For purposes of example, the prior art electricity meter 100 is configured as a Form 2S service type electricity meter, which is a meter configured for use with a single phase, three wire service.

The prior art electricity meter 100 is installed in series with a load 105, which for purposes of exemplifying a residential load is depicted as a house.

In use, a high-voltage power supply line 110 may provide a supply of electrical power from the grid, i.e. from a utility company. A transformer 115 may step down a voltage on the power supply line 110 to a voltage suitable for use by the load 105, e.g. 240 volts or 110 volts, or the like.

5 In the example electricity meter 100, a first input terminal 120a is connected to a supply voltage from the transformer 115 having a first phase and a second input terminal 120c is connected to a supply voltage from the transformer 115 having a second phase. The second phase is out of phase with the first phase. For example, the second phase may be an anti-phase, e.g. 180 degrees out of phase with the first phase. The first input
10 terminal 120a may be known in the art as a "Phase A" input. The second input terminal 120c may be known in the art as a "Phase C" input.

A first output terminal 140a and a second output terminal 140c are connected to the load 105, and therefore can provide electrical power to the load 105.

15 The example electricity meter 100 comprises a first actuatable switch S1 and a second actuatable switch S2. The first actuatable switch S1 may selectively disconnect/connect the grid-side first input terminal 120a from the load-side first output terminal 140a. The second actuatable switch S2 may selectively disconnect/connect the grid-side second input terminal 120c from the load-side second output terminal 140c.

20 In use, the first actuatable switch S1 and the second actuatable switch S2 may be collectively known as a 'service disconnect switch', and may be configured to selectively connect/disconnect the load-side from the grid-side of the electricity meter 100. That is, the first actuatable switch S1 may selectively couple the first input terminal 120a to the first output terminal 140a and the second actuatable switch S2 may selectively couple the second input terminal 120c to the second output terminal 140c.

25 The example electricity meter 100 comprises measurement circuitry 130. The measurement circuitry 130 comprises an Analog Front End, denoted 'AFE' in Figure 1. The measurement circuitry 130, and in particular the AFE, may comprise analog-to-digital converters, anti-aliasing filters, and the like. The analog front end may be communicably coupled to control circuitry and/or processing circuitry (not shown). The
30 analog front end may be configured to perform analog measurements of the grid-side voltage and/or load-side voltage and/or current, and convert such measurements into digital signals for communication to the control circuitry, as described further below.

A 'Phase A' input voltage level at the first input terminal 120a, e.g. at the grid-side of the first actuatable switch S1, may be measured by the measurement circuitry

130, such as by sensing a voltage at a string of resistors (not shown) at a first node 135a coupled to the first input terminal 120a.

A 'Phase C' input voltage level at the second input terminal 120c, e.g. at the grid-side of the second actuatable switch S2, may be measured by the measurement circuitry 130, such as by sensing a voltage at a string of resistors (not shown) at a second node 135c coupled to the second input terminal 120c.

A 'Phase A' output voltage level at the first output terminal 140a, e.g. at the load-side of the first actuatable switch S1, may be measured by the measurement circuitry 130, such as by sensing a voltage at a string of resistors (not shown) at a third node 145a coupled to the first output terminal 140a.

A 'Phase C' output voltage level at the second output terminal 140c, e.g. at the load-side of the second actuatable switch S2, may be measured by the measurement circuitry 130, such as by sensing a voltage at a string of resistors (not shown) at a fourth node 145c coupled to the second output terminal 140c.

The electricity meter 100 also comprises a first current transformer 150a for providing a signal to the measurement circuitry 130 corresponding to a 'Phase A' current at the load-side of the first actuatable switch S1.

The electricity meter 100 also comprises a second current transformer 150c for providing a signal to the measurement circuitry 130 corresponding to a phase C current at the load-side of the second actuatable switch S2.

Figure 2 depicts a more detailed example of a prior art electricity meter 200, generally corresponding to the Form 2S electricity meter 100 of Figure 1, but showing in more detail specific components of the electricity meter 200.

The prior art electricity meter 200 is installed in series between a grid 215 and a load 205.

In the example electricity meter 200, a first input terminal 220a is connected to a supply voltage from the grid 215 having a first phase and a second input terminal 220c is connected to a supply voltage from the grid 215 having a second phase, wherein the second phase is out of phase with the first phase.

The first input terminal 220a and the second input terminal 220c may be provided at a service entrance of the electricity meter 200.

The first input terminal 220a may be known in the art as a "Phase A" input. The second input terminal 220c may be known in the art as a "Phase C" input.

A first output terminal 240a and a second output terminal 240c are connected to the load 205, and therefore can provide electrical power to the load 205.

The example electricity meter 200 comprises service disconnect switch 295, which may selectively disconnect/connect the grid 215 from the load 205.

The electricity meter 200 comprises an actuator 265 which may, for example, comprises a solenoid or the like for actuating the service disconnect switch 295.

5 The example electricity meter 200 comprises measurement circuitry 230. The measurement circuitry 230 comprises an analog front end 270. The measurement circuitry 230, and in particular the analog front end 270, may comprise analog-to-digital converters, anti-aliasing filters, and the like. In the example, the analog front end 270 is communicably coupled to digital circuitry 275. The analog front end 270 may be
10 configured to perform analog measurements of the grid-side voltage and load-side voltage and current, and convert such measurements into digital signals for processing by the digital circuitry 275. In some examples, data corresponding to the processed measurements may be communicated to a remote device, such as another electricity meter in a mesh network, by the digital circuitry 275 which may comprise
15 communications circuitry such as a transceiver.

A grid voltage sensing circuit 280G, denoted V_SENSE_{GRID} , is configured for determining a voltage on each of the first and second input terminals 220a, 220c, thereby providing grid-side voltage measurements. The grid voltage sensing circuit 280G may be implemented using relatively expensive resistor strings (not shown), which are
20 described in more detail below with reference to Figure 3. Such expensive resistor strings may be capable of tolerating substantial voltage spikes and current surges, such as those that may be incurred due to a lightning strike. Such resistor strings may substantially contribute to an overall cost of manufacturing the electricity meter 200. The grid voltage sensing circuit 280G is coupled to the analog front end 270, enabling measurements of
25 the grid-side voltage

Similar to the electricity meter 100 of Figure 1, the electricity meter 200 also comprises a load voltage sensing circuit 280L, denoted V_SENSE_{LOAD} , for sensing a voltage across the load 205, at a load-side of the service disconnect switch 295. The load voltage sensing circuit 280L is also coupled to the analog front end 270, enabling
30 measurements of the load-side voltage. The load voltage sensing circuit 280L may also implement relatively expensive resistor strings.

A 'Phase A' electrical current flowing to the load 205 from the first input terminal 220a may be measured, for purposes of determining electrical power consumption by the load 205, using a first current sensing circuit 290a, denoted $I_SENSE_{PHASE_A}$. The
35 first current sensing circuit 290a may comprise a current transformer. The first current

sensing circuit 290a is coupled to the measurement circuitry 230, e.g. to one or more ADC channels of the analog front end 270.

A 'Phase C' electrical current flowing to the load 205 from the second input terminal 220c may be measured, for purposes of determining electrical power consumption by the load 205, using a second current sensing circuit 290c, denoted
5 I_SENSE_{PHASE_A}. The second current sensing circuit 290c may comprise a current transformer. The second current sensing circuit 290c is coupled to the measurement circuitry 230, e.g. to one or more ADC channels of the analog front end 270.

The electricity meter 200 comprises a power supply 260. The power supply 260
10 receives power from the grid 215 via the first input terminal 220a and the second input terminal 220c. The power supply 260 provides power to components of the electricity meter 200. In the example, the power supply 260 provides electrical power to the actuator 265. The power supply 260 also provides electrical power to the measurement circuitry 230. In examples, the power supply 260 may comprise at least one rectifier
15 and/or regulator circuit configured to supply power to the measurement circuitry 230 and the actuator 265. For example, the power supply 260 may comprise a rectifier, such as a bridge rectifier, configured to provide a direct current output from an alternating current input at the input to the power supply 260. The power supply 260 may comprise one or
20 more regulators configured to provide a range of voltages suitable for operation of different components of the smart meter. As an example, the power supply 260 may be configured to provide a 24 volt direct current supply to the actuator 265, a 5 volt direct current supply to the analog front end 270, and a 3.3V direct current supply to a microprocessor circuit within the digital circuitry 275.

Figure 3 depicts a portion of a service disconnect switch 295 comprising plurality
25 of contacts, in particular the service disconnect switch 295 is shown as having two contacts 296a, 296b per phase (which may be made from silver and/or other suitable materials) to provide redundancy due to the wear described above. In other examples, three contacts per phase may be implemented in a service disconnect switch 295. As will be described in more detail below, embodiments of the present disclosure enable
30 the elimination of the need to provide multiple contacts in a service disconnect switch 295 and/or the reduction in thickness of the contact(s) used in a service disconnect switch 295.

Figure 4 depicts an electricity meter 400 according to an embodiment of the disclosure. The electricity meter 400 includes components of the electricity meter 200
35 and therefore corresponding reference numerals have been used where appropriate.

Some features (such as the power supply 260) have been omitted from Figure 4 for clarity.

As shown in Figure 4, the electricity meter 400 comprises a processor 402 coupled to a memory 403. The processor 402 may correspond to the microprocessor within the digital circuitry 275 referred to above. The functionality of the processor 402 described herein may be implemented in code (software or firmware) stored on a memory (e.g. memory 403) comprising one or more storage media, and arranged for execution on a processor comprising one or more processing units. The storage media may be integrated into and/or separate from the processor 402. The code is configured so as when fetched from the memory and executed on the processor to perform operations in line with embodiments discussed herein. Alternatively it is not excluded that some or all of the functionality of the processor 402 is implemented in dedicated hardware circuitry, or configurable hardware circuitry like an FPGA.

The processor 402 is coupled to the memory 403 to enable the processor 402 to store data in the memory 403 and retrieve data from the memory 403.

The processor 402 is also coupled to a temperature sensor 404. The temperature sensor 404 is configured to sense the temperature in the environment of the electricity meter 400, and therefore a temperature in the environment of the service disconnect switch 295a and the service disconnect switch 295b. The temperature sensor 404 is configured to output a temperature signal to the processor 402, the temperature signal indicative of the temperature in the environment of the electricity meter 400.

As shown in Figure 4, a service disconnect switch 295a is provided on the connection between the first input terminal 220a and the first output terminal 240a, and a service disconnect switch 295b is provided on the connection between the second input terminal 220c and the second output terminal 240c.

The processor 402 is coupled to the actuator 265. The actuator is coupled to both the service disconnect switches 295a and 295b.

In the example of Figure 4, the processor 402 is configured to output a first control signal to the actuator 265 on a connection 406 between the processor 402 and the actuator 265. The actuator 265 is configured to output a switching signal on a connection 408 between the actuator 265 and the service disconnect switch 295a to change a switching state of the service disconnect switch 295a, in dependence on a value of the first control signal. Furthermore, the processor 402 is configured to output a second control signal to the actuator 265 on a connection 410 between the processor 402 and the actuator 265. The actuator 265 is configured to output a switching signal on a

connection 412 between the actuator 265 and the service disconnect switch 295b to change a switching state of the service disconnect switch 295b, in dependence on a value of the second control signal. Whilst two separate connections 406,410 are shown between the processor 402 and the actuator 265 it will be appreciated that this is merely
5 an example and there may be a single connection between the processor 402 and the actuator 265. The actuator 265 may be configured to convert the low power control signals received from the processor 402 to high power control signals to control the service disconnect switches 295a and 295b.

The actuator 265 may comprise an electric motor. It will be appreciated that
10 temperature affects the operation of an electric motor. Optionally the actuator 265 may comprise a gearbox coupled to the electric motor. The gearbox has grease (or other lubricant) in it that will have different friction (viscosity) coefficients based on temperature. The motor actuation can take several tens of milliseconds and this is not predictable due to the variation in the temperature and other factors including mechanical variations such
15 as friction, viscosity of lubricants, etc. Therefore, the timing for output of a control signal from the processor 402 to the actuator 265 such that a switching state of the switch will change when a monitored waveform reaches a target point cannot simply be coded into firmware/software running on the processor 402.

The actuator 265 may comprise a solenoid or a relay. It will be appreciated that
20 temperature affects the operation of both a solenoid and a relay.

The processor 402 may be coupled to an analog front end 270.

The electricity meter 400 comprises the grid voltage sensing circuit 280G (not shown in Figure 4) to determine a voltage on each of the first and second input terminals 220a, 220c. The grid voltage sensing circuit 280G is configured to output the measured
25 voltage on each of the first and second input terminals 220a, 220c, illustrated as "Line Side V Sense". The processor 402 is arranged to receive the measured voltage on each of the first and second input terminals 220a, 220c from the grid voltage sensing circuit 280G, or from the AFE 270 (in embodiments in which the processor 402 is coupled to the AFE 270).

30 The electricity meter 400 comprises the first current sensing circuit 290a (not shown in Figure 4) to measure the 'Phase A' electrical current flowing to the load 205 from the first input terminal 220a. The first current sensing circuit 290a is configured to output the measured 'Phase A' electrical current, illustrated as "Phase A Current Sense". The processor 402 is arranged to receive the measured 'Phase A' electrical current from

the first current sensing circuit 290a or from the AFE 270 (in embodiments in which the processor 402 is coupled to the AFE 270).

5 The electricity meter 400 comprises the second current sensing circuit 290c (not shown in Figure 4) to measure the 'Phase C' electrical current flowing to the load 205 from the second input terminal 220c. The second current sensing circuit 290c is configured to output the measured 'Phase C' electrical current, illustrated as "Phase C Current Sense". The processor 402 is arranged to receive the measured 'Phase C' electrical current from the second current sensing circuit 290c or from the AFE 270 (in embodiments in which the processor 402 is coupled to the AFE 270).

10 The electricity meter 400 comprises the load voltage sensing circuit 280L (not shown in Figure 4) for sensing a voltage across the load 205, at a load-side of the service disconnect switches 295a and 295b. The load voltage sensing circuit 280L is configured to output the measured voltage on the load-side of the service disconnect switches 295a and 295b. The processor 402 is arranged to receive the measured voltage on the load-side of the service disconnect switches 295a and 295b from the load voltage sensing circuit 280L, or from the AFE 270 (in embodiments in which the processor 402 is coupled to the AFE 270).

In embodiments of the present disclosure, the processor 402 uses a switch characterization tool in order to determine an estimated switching time period between
20 (i) output of a control signal from the processor 402 to the actuator 265 and (ii) a change of the switching state of a service disconnect switch 295. The processor 402 then makes adjustments to the timing of when a control signal is output by the processor 402 to the actuator 265 (to control the switching state of a service disconnect switch 295) in an attempt that the switching state of the switch changes when a monitored waveform
25 reaches a target point. The processor 402 monitors at least one load-side waveform to determine actual switching time period, such that each switch operation provides additional data to update the switch characterization tool to further refine the estimation of the switching time period (and optionally also determine which variables are the most critical for a given situation).

30 An initial switch characterization tool may be prestored in memory 403 during manufacture of the electricity meter 400 for access by the processor 402. For example, the initial switch characterization tool may be seeded at the time of manufacture based on characterization data (and possibly field data). The characterization data used to seed the initial switch characterization tool may be from an aggregate of meters
35 characterized. This initial switch characterization tool will transition from being generic to

specific to the actual electricity meter 400 based on the actual meter characteristics. An open and close of the service disconnect switch 295 may be performed during manufacturing to provide the first device specific data for the switch characterization tool. The initial switch characterization tool prestored in memory 403 may be a look-up table (LUT), an equation or a machine learning model.

Alternatively, the initial switch characterization tool may be generated by the processor 402. In both examples, the processor 402 is configured to update the switch characterization tool over time.

Figure 5 illustrates a flowchart of a method 500 of generating a switch characterization tool.

At step S502, the processor 402 determines that the switching state of a service disconnect switch 295 is to be changed. The processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed in a number of different ways. In one example, the processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command via an optical port of the electricity meter (not shown in Figure 4). In another example, the processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command in response to selection of one or more buttons on the electricity meter (not shown in Figure 4). In another example, the processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command. The electricity meter 400 may comprise a communications unit (not shown in Figure 4) to allow radio frequency transmissions to be received from other electricity meters and/or a server. In another example, the processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command via the communications unit.

In response to the processor 402 determining that the switching state of a service disconnect switch 295 is to be changed, at step S504 the processor 402 outputs a control signal to the actuator 265. For example, the processor 402 may output the control signal on connection 406 to the actuator 265 in order to control the switching state of the service disconnect switch 295a, and output the control signal on connection 410 to the actuator 265 in order to control the switching state of the service disconnect switch 295b (the service disconnect switch 295b and the service disconnect switch 295b switch together). The processor 402 is configured to log a timestamp (t) when the control signal was output to the actuator 265, in memory 403. The timestamp (t) may be in the order of milliseconds.

At step S506, the processor 402 logs switch characterization data that is associated with the service disconnect switch 295 in memory 403. The switch characterization data defines the conditions of the service disconnect switch 295 when the control signal was output to the actuator 265 at timestamp (t). For example, the switch characterization data may define the temperature in an environment of the electricity meter 400 (determined based on a temperature signal received from the temperature sensor 404). Alternatively or additionally, the switch characterization data may define a number of switch actuations performed by the service disconnect switch 295 since manufacture of the electricity meter 400. The processor 402 may be configured to maintain a counter in memory 403 to indicate the number of switch actuations of the service disconnect switch 295. This enables the processor 402 to query the memory 403 to determine the number of switch actuations performed by the service disconnect switch 295. Alternatively or additionally, the switch characterization data may define the age of the service disconnect switch 295. The age of the service disconnect switch 295 may be maintained in memory 403 such that the processor 402 can query the memory 403 to determine the age of the service disconnect switch 295. The age of the service disconnect switch 295 may be measured from the manufacture date of the service disconnect switch 295. It will be appreciated that the age of the service disconnect switch 295 may be measured in hours, days, weeks etc.

At step S508, the processor 402 monitors at least one load-side waveform of the electricity meter on a connection between the service disconnect switch 295 and a load-side output terminal to detect an actual switching time period between (i) the output of the control signal and (ii) a change of the switching state of the switch. For example, in respect of the service disconnect switch 295a, the processor 402 monitors at least one load-side waveform on the connection between the service disconnect switch 295a and the first output terminal 240a. In respect of the service disconnect switch 295b, the processor 402 monitors at least one load-side waveform on the connection between the service disconnect switch 295b and the second output terminal 240c. At step S508, the processor 402 monitors a load-side voltage waveform and/or a load-side current waveform.

At step S510, the processor 402 generates a switch characterization tool using the actual switching time period and the switch characterization data.

In particular, in embodiments whereby the switch characterization tool is a LUT, at step S510 the processor 402 generates the LUT with an entry including the actual switching time period and the switch characterization data to indicate the actual switching

time period that was measured when the service disconnect switch 295 was operating under the conditions defined by the switch characterization data. Once the electricity meter has been deployed and is in operation, the LUT would be supplemented based on real time measurements of the meter.

5 In embodiments whereby the switch characterization tool is an equation or set of equations, the processor 402 generates the equation(s) defining the relationship between the actual switching time period and the switch characterization data. The equation(s) may define multiple terms and coefficients (which can be updated as described later). In particular, a LUT may be reduced to an equation or set of equations
10 with multiple terms and coefficients, without the need for a LUT.

 In other embodiments, the actual switching time period and the switch characterization data may be used as first piece of training data to generate a machine learning model.

 In embodiments of the present invention, for each subsequent switch actuation
15 the processor 402 uses, and then updates, the switch characterization tool. That is, each subsequent switch actuation provides additional data to refine the switch characterization tool.

 As explained above an initial switch characterization tool may be prestored in memory 403 during manufacture of the electricity meter 400 for access by the processor
20 402.

 Figure 6 a flowchart of a method of using and modifying a switch characterization tool. Figure 6 is performed by the processor 402 at a time when a switch characterization tool is stored in memory 403 and accessible to the processor 402. For example, a switch characterization tool has been prestored in memory 403 during manufacture of the
25 electricity meter 400 for access by the processor 402, or a switch characterization tool has already been generated by the processor 402 (e.g. using the method 500).

 At step S602, the processor 402 determines that the switching state of a service disconnect switch 295 is to be changed. The processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed in a number of
30 different ways. In one example, the processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command via an optical port of the electricity meter (not shown in Figure 4). In another example, the processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command in response to selection of one or more
35 buttons on the electricity meter (not shown in Figure 4). In another example, the

processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command. The electricity meter 400 may comprise a communications unit (not shown in Figure 4) to allow radio frequency transmissions to be received from other electricity meters and/or a server. In another example, the
5 processor 402 may determine that the switching state of a service disconnect switch 295 is to be changed based on receiving a command via the communications unit.

At step S604, the processor 402 uses the switch characterization tool stored in memory 403 to determine an estimated switching time period between (i) output of a control signal from the processor 402 to the actuator 265 and (ii) a change of the
10 switching state of the service disconnect switch 295. In particular, the processor 402 detects switch characterization data which defines the conditions of the service disconnect switch 295 and uses both the switch characterization data and the switch characterization tool to determine the estimated switching time period. As explained above, the switch characterization data may define one or more of the temperature in an
15 environment of the electricity meter 400, a number of switch actuations performed by the service disconnect switch 295 since manufacture of the electricity meter 400, an age of the service disconnect switch 295. That is, at step S604 the processor 402 looks up the characterization of the service disconnect switch 295 using the switch characterization tool based on the current temperature, number of switch actuations that have been
20 performed and/or the age of the service disconnect switch 295.

As a mere example to illustrate the concept, the processor 402 may determine an estimated switching time period of 10ms. That is, the processor 402 estimates that under the current conditions it will take 10ms after the processor 402 outputs a control signal to the actuator 265, before the switching state of the service disconnect switch
25 295 will change.

At step S606, the processor 402 monitors a waveform. When the service disconnect switch 295 is in a closed state, the processor 402 may monitor any of a grid-side voltage waveform, a grid-side current waveform, a load-side voltage waveform, or a load-side current waveform. For example, for service disconnect switch 295a, the
30 processor 402 may monitor the voltage or current on the connection between the first input terminal 220a and the service disconnect switch 295a or the voltage or current on the connection between the service disconnect switch 295a and the first output terminal 240a. When the service disconnect switch 295 is in an open state, the processor 402 may monitor a grid-side voltage waveform. For example, for service disconnect switch

295a, the processor 402 may monitor the voltage on the connection between the first input terminal 220a and the service disconnect switch 295a.

At step S608, the processor 402 uses the monitored waveform and the estimated switching time period to determine an output time at which to output a control signal to the actuator 265 such that the switching state of the switch will change when the waveform reaches a target point. That is, using the monitored waveform the processor 402 can estimate when the target point (e.g. a zero crossing of the monitored waveform, or when the monitored waveform is at 30 or 45 degrees from a zero crossing) will occur and then back-calculate when the processor 402 should output the control signal using the estimated switching time period. In some applications, the target point may be a zero crossing of the monitored waveform. In some applications, it may be desirable to avoid the switching state of the service disconnect switch changing when the waveform reaches a zero crossing of the monitored waveform, for example when there is a highly inductive load as this can cause much higher currents to be seen than are desirable. In these applications, the target point may be set to at least 20 degrees from a zero crossing, for example at least 30 degrees from a zero crossing, at least 40 degrees from a zero crossing, or at least 45 degrees from a zero crossing.

At step S610 the processor 402 outputs a control signal to the actuator 265. For example, the processor 402 may output the control signal on connection 406 to the actuator 265 in order to control the switching state of the service disconnect switch 295a. Alternatively or additionally, the processor 402 may output the control signal on connection 410 to the actuator 265 in order to control the switching state of the service disconnect switch 295b. The processor 402 is configured to log a timestamp (t1) when the control signal was output to the actuator 265, in memory 403. The timestamp (t1) may be in the order of milliseconds.

The processor 402 is configured to log the switch characterization data (detected at step S604) in memory 403.

At step S612, the processor 402 monitors at least one load-side waveform of the electricity meter on a connection between the service disconnect switch 295 and a load-side output terminal to detect an actual switching time period between (i) the output of the control signal occurring at the timestamp (t1) and (ii) a change of the switching state of the switch occurring at a timestamp (t2). For example, in respect of the service disconnect switch 295a, the processor 402 monitors at least one load-side waveform on the connection between the service disconnect switch 295a and the first output terminal 240a. In respect of the service disconnect switch 295b, the processor 402 monitors at

least one load-side waveform on the connection between the service disconnect switch 295b and the second output terminal 240c. At step S612, the processor 402 monitors a load-side voltage waveform and/or a load-side current waveform.

5 The monitoring of the at least one load-side waveform allows the processor 402 to detect when a change of the switching state of the switch occurs and to log a timestamp of this at timestamp (t2). For example, the processor 402 may detect the occurrence of a change of switching state of the service disconnect switch 295 when the load-side voltage waveform increases from a non-zero voltage value (when the service disconnect switch closes) or decreases to a zero voltage value (when the service disconnect switch open). The processor 402 is configured to calculate the actual switching time period by determining the time difference between timestamp (t1) and timestamp (t2).

10 At step S614, the processor 402 modifies the switch characterization tool based on the actual switching time period. In particular, the processor 402 modifies the switch characterization tool based on the actual switching time period and the switch characterization data.

15 In particular, in embodiments whereby the switch characterization tool is a LUT, at step S614 the processor 402 modifies the LUT based on the actual switching time period and the switch characterization data. Each actuation of the service disconnect switch 295 would provide new data for the LUT. That is, during operation of the electricity meter 400 additional data would be added to the LUT based on real time measurements of that meter.

20 The LUT may be a multi-dimensional lookup table with at least number of cycles, temperature, and prior information being the inputs. As an example, an initial LUT may be prestored in memory 403 that has 10 entries. After 100 operations of the service disconnect switch 295, there may be up to 110 entries in the LUT. The prior information would be the 100 prior logs when the 101st switch cycle occurs.

25 The initial LUT may comprise certain temperature data points e.g. -40, -20, 0, 25, 50, 85 °F paired with a different number of switch actuations, with delays from the nominal being logged in the LUT (i.e. switching time period). This initial LUT would then be updated accordingly to provide a refined approach.

30 Additionally, in embodiments whereby the electricity meter 400 is coupled to a communication network, the LUT stored on the electricity meter 400 may be updated based on actual switching time period data received (via the communication network) from other electricity meters that are also coupled to the communication network.

Alternatively, or additionally the LUT stored on the electricity meter 400 may be updated by way of a firmware update prepared based on actual switching time period data measured by other electricity meters.

In embodiments whereby the switch characterization tool is an equation, at step
5 S614 the processor 402 may modify one or more coefficients in the equation. That is, an equation defining a slope that is established based on generic data at the point of manufacture may be modified by the processor 402 based on device specific actual switching time period data to adjust the intercept of the slope.

In embodiments, whereby the switch characterization tool is machine learning
10 model, the actual switching time period and the switch characterization data would provide further training data to supplement previously used training data in order to re-train the machine learning model.

In embodiments, whereby the switch characterization tool is either an equation
15 or a machine learning model, a LUT (or at least a data set) may additionally be stored in the memory 403. For example, a running log of the conditions of the electricity meter 400 and the associated measured actual switching time period data, may be stored in the memory 403.

As shown in Figure 6, the method 600 is an iterative process such that the switch
20 characterization tool can be continually updated after each actuation of the service disconnect switch 295 (if it is necessary to do so). It will be appreciated that when using an initial switch characterization tool initial wear of the contacts of a service disconnect switch 295 will be more severe, but the continual learning will allow the processor 402 to hone in on the service disconnect switch 295 switching state at the target point on the waveform monitored at step S606 and allow for lower wear over time.

In embodiments of the present disclosure the switch characterization tool may
25 also be updated by a dedicated update process (i.e. in addition to the process shown in Figure 6). For example the switch characterization tool can be updated by way of a firmware or software update. This update may be performed based on characterization of the service disconnect switch 295 by the manufacturer of the service disconnect switch
30 295 and/or based on real life actual switching time period data observed by other electricity meters in operation.

Whilst examples of the switch characterization tool have been described above,
it will be appreciated that these are merely examples and embodiments of the present
disclosure extend to other switch characterization tools which can be used to
35 characterize the operation of the service disconnect switch 295 and be updated.

Although the disclosure has been described in terms of particular embodiments as set forth above, it should be understood that these embodiments are illustrative only and that the claims are not limited to those embodiments. Those skilled in the art will be able to make modifications and alternatives in view of the disclosure, which are contemplated as falling within the scope of the appended claims. Each feature disclosed or illustrated in the present specification may be incorporated in any embodiments, whether alone or in any appropriate combination with any other feature disclosed or illustrated herein.

LIST OF REFERENCE NUMERALS

	100	electricity meter		260	power supply
	105	load		265	actuator
5	110	power-supply line		270	analog front end
	115	transformer		275	digital circuitry
	120a	first input terminal	30	280G	grid voltage sensing circuit
	120c	second input terminal		280L	load voltage sensing circuit
	130	measurement circuitry		290a	first current sensing circuit
10	135a	first node		290c	second current sensing circuit
	135c	second node		295	service disconnect switch
	140a	first output terminal	35	295a	service disconnect switch
	140c	second output terminal		296a	service disconnect switch
	145a	third node		296a	service disconnect switch
15	145c	fourth node			contact
	150a	first current transformer		296b	service disconnect switch
	150c	second current transformer	40		contact
	200	electricity meter		400	electricity meter
	205	load		402	processor
20	215	grid		403	memory
	220a	first input terminal		404	temperature sensor
	220c	second input terminal	45	406	connection
	230	measurement circuitry		408	connection
	240a	first output terminal		410	connection
25	240c	second output terminal		412	connection

CLAIMS

1. An electricity meter comprising:
 - a grid-side input terminal and a load-side output terminal;
 - 5 a switch coupled between the grid-side input terminal and the load-side output terminal;
 - an actuator coupled to the switch, the actuator configured to output a switching signal to the switch to change a switching state of the switch; and
 - a processor arranged to output a control signal to the actuator to cause
 - 10 the output of the switching signal; wherein the processor is configured to:
 - determine, at a determination time, that the switching state of the switch is to be changed;
 - use a switch characterization tool, to determine an estimated switching time period between (i) output of a control signal from the
 - 15 processor to the actuator and (ii) a change of the switching state of the switch;
 - monitor a waveform of the electricity meter;
 - determine from the waveform and the estimated switching time period, an output time at which to output the control signal such that the
 - 20 switching state of the switch changes when the waveform reaches a target point;
 - output the control signal to the actuator at the output time, to cause the output of the switching signal from the actuator to the switch;
 - monitor at least one load-side waveform of the electricity meter on
 - 25 a connection between the switch and the load-side output terminal to detect an actual switching time period between (i) the output of the control signal and (ii) a change of the switching state of the switch; and
 - modify the switch characterization tool based on the actual switching time period.
- 30 2. The electricity meter of claim 1, wherein the waveform of the electricity meter is a grid-side waveform present on a connection between the grid-side input terminal and the switch.

3. The electricity meter of claim 2, wherein the processor is configured to monitor the grid-side waveform of the electricity meter whilst the switch is in a closed state.
4. The electricity meter of claim 3, wherein the grid-side waveform is a grid-side voltage waveform.
- 5
5. The electricity meter of claim 3, wherein the grid-side waveform is a grid-side current waveform.
- 10
6. The electricity meter of claim 2, wherein grid-side waveform is a grid-side voltage, and the processor is configured to monitor the grid-side waveform of the electricity meter whilst the switch is in an open state.
- 15
7. The electricity meter of claim 1, wherein the waveform of the electricity meter is a load-side waveform present on the connection between the switch and the load-side output terminal.
- 20
8. The electricity meter of claim 7, wherein the load-side waveform is a load-side voltage waveform.
9. The electricity meter of claim 7, wherein the load-side waveform is a load-side current waveform.
- 25
10. The electricity meter of any preceding claim, wherein the at least one load-side waveform of the electricity meter comprises one or both of a load-side voltage waveform and a load-side current waveform.
- 30
11. The electricity meter of any preceding claim, wherein the actuator comprises an electric motor.
12. The electricity meter of any of claims 1 to 10, wherein the actuator comprises a solenoid.

13. The electricity meter of any of claims 1 to 10, wherein the actuator comprises a relay.
14. The electricity meter of any preceding claim, wherein the processor is configured to use a temperature in an environment of the electricity meter at said determination time, to determine the estimated switching time period.
15. The electricity meter of any preceding claim, wherein the processor is configured to use an age of the switch to determine the estimated switching time period.
16. The electricity meter of any preceding claim, wherein the processor is configured to use a number of switch actuations performed by the switch to determine the estimated switching time period.
17. The electricity meter of any preceding claim, wherein the switch characterization tool is a look-up table.
18. The electricity meter of any preceding claim, wherein the switch characterization tool is an equation.
19. The electricity meter of any preceding claim, wherein the switch characterization tool is a machine learning model.
20. The electricity meter of any preceding claim, wherein the target point is a zero crossing of the waveform.
21. A method of operating an electricity meter, the method comprising:
determining, at a determination time, that a switching state of a switch of the electricity meter is to be changed, the switch coupled between a grid-side input terminal and a load-side output terminal of the electricity meter;
using a switch characterization tool, to determine an estimated switching time period between (i) output of a control signal to an actuator coupled to the switch and (ii) a change of the switching state of the switch;
monitoring a waveform of the electricity meter;

determining from the waveform and the estimated switching time period, an output time at which to output the control signal such that the switching state of the switch will change when the waveform reaches a target point;

outputting the control signal to the actuator at the output time, to cause the output
5 of a switching signal from the actuator to the switch;

monitoring at least one load-side waveform of the electricity meter on a connection between the switch and the load-side output terminal to detect an actual switching time period between (i) the output of the control signal and (ii) a change of the switching state of the switch; and

10 modifying the switch characterization tool based on the actual switching time period.

22. A non-transitory computer-readable storage medium comprising instructions for operating an electricity meter, the instructions when executed by a processor of the
15 electricity meter cause the processor to:

determine, at a determination time, that a switching state of a switch of the electricity meter is to be changed, the switch coupled between a grid-side input terminal and a load-side output terminal of the electricity meter;

use a switch characterization tool, to determine an estimated switching time
20 period between (i) output of a control signal to an actuator coupled to the switch and (ii) a change of the switching state of the switch;

monitor a waveform of the electricity meter;

determine from the waveform and the estimated switching time period, an output time at which to output the control signal such that the switching state of the switch will
25 change when the waveform reaches a target point;

output the control signal to the actuator at the output time, to cause the output of a switching signal from the actuator to the switch;

monitor at least one load-side waveform of the electricity meter on a connection between the switch and the load-side output terminal to detect an actual switching time
30 period between (i) the output of the control signal and (ii) a change of the switching state of the switch; and

modify the switch characterization tool based on the actual switching time period.