ADDAX

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ADDAX Meters
Tamper-Proof &
Anti-Fraud Features

General Description

2010

Revision History

Version	Date	Author	Comments
1.0	29.09.10	Deinikovskaia N.	Original document
2.0	04.10.10	Deinikovskaia N.	Section “Meter Manipulated Detection” is added

ADDAX Meter

Single phase/three phase ADDAX meters are solid state smart devices for active and reactive energy metering. The meters are designed to measure instantaneous power and consumed active and reactive energy in single-phase/three-phase alternating current circuits. The meters are used by end-consumers to make individual payments to the electrical energy supplier.

ADDAX meters design allows efficient fraud and tamper detection and decrease of common loss level.

A tamper condition takes place, when the meter is connected in a fraudulent manner, typically with the intention to reduce electricity billing. The meter detects, signals and continues to measure accurately a number of tamper conditions and fraud attempts.

Tamper Detection:

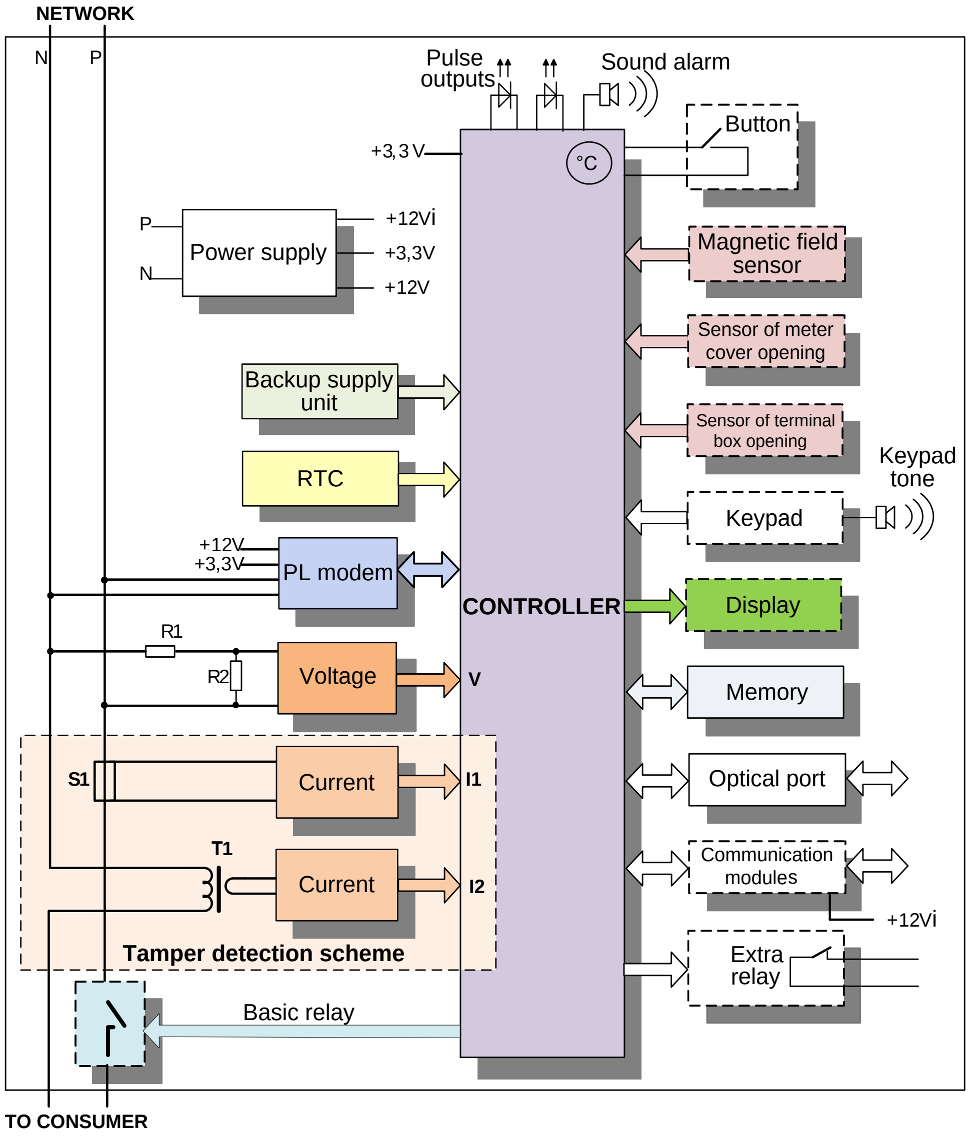
- Partial earth fault;
- Reverse current;
- Phase and neutral wire swapped;
- Missing neutral;
- Missing potential;
- Bypassing the meter;
- Double feeding the meter.

Meter Manipulated Detection:

- Meter case opening;
- Terminal box opening;
- Strong external magnetic field;
- Tariffs manipulation;
- Unauthorized access.

Meter design:

As an example, block-diagram for the single-phase meter is illustrated. The basic components for the three-phase meter are the same. Units, marked with dotted lines, are optional and are available in the meter depending on the meter type. Colored units take part in the tamper detection and control.



The basic functional unit of the meter is a ***microcontroller***. It processes measured voltage, current and temperature signals from the respective sensors and converts results obtained to the digital code. Measuring results are then placed in the ***non-volatile memory*** and are transmitted to the Master Station via communication channels and/or displayed at the meter ***display***. The controller also performs switching-off relay control (via the ***basic relay***) and secondary load control (via the ***extra relay***). Besides this controller registers terminal box and meter case opening events as well as strong external magnetic field presence for meter manipulated detection.

To store measuring data, calibration factors and configuration as well as to working software remote upgrade the meter ***memory*** is intended.

Metering data and events are provided with the timestamps assured by the ***real time clock (RTC)***. The clock provides support of TOU tariff metering and assures processing of control commands according to the set schedule. RTC is continuously synchronized with the system clock via data transfer network and is supported by the ***backup supply unit*** when the power is off.

To provide data transfer between the meter and external system (router/concentrator) ***PL modem*** is used. Data include meter readings, events and alarms (including fraud events) the same as commands to control the relay.

To provide customer with detailed information on electrical energy consumption and events (including fraud attempts) ***liquid crystal display (LCD)*** is used.

The meter uses a ***tamper detection scheme*** for tamper-proof measures. The single-phase meter scheme includes two measuring channels: in the phase circuit and in the neutral circuit. Tamper detection is based on monitoring current flow in both phase and neutral wires. A precision shunt for the 1st measuring channel is used. To measure neutral current (the 2nd measuring channel) differential current sensor or a current transformer are applied (depending on meter model).

For three-phase meter[1] current transformers to measure phase currents are applied in each phase. To measure neutral current also current transformer is used.

If any inconsistency between phase and neutral currents is detected, it can be used as an indicator of tampering attempts. For example: if difference between currents in phase and neutral exceeds a certain specified value or currents flow in directions opposite to the normal. When a tamper is detected, respective symbol can be displayed on the meter LCD and/or controller can switch consumer off from the network with the help of breaking relay.

A ***precision divider*** to measure voltage is used. Divider diminishes input voltage up to convenient for metering scheme value. Voltage division is performed with optimal linearity at minimal phase shift.

To protect the meter from extra tampering a ***terminal box cover opening sensor*** and ***meter case opening sensor*** are provided in the meter structure (optional, depending on meter model). The sensors operating when the power is off is also supported due to the meter ***backup power supply***.

To register external magnetic field a ***magnetic field sensor*** is intended (reed switch or Hall sensor, depending on the meter model).

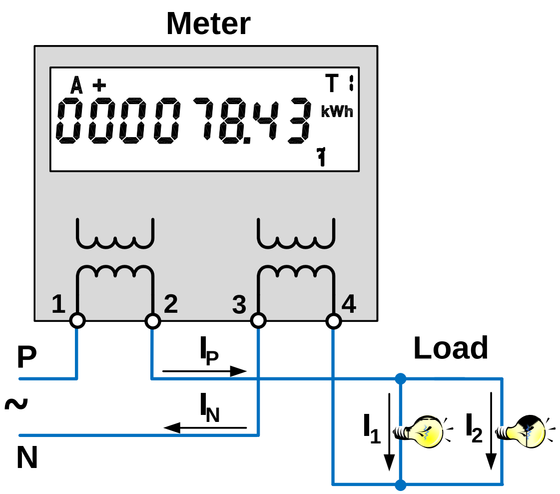
For more details about other units of the meter, not described in this document, as well as the meter technical description apply to annexes A1 and A2.

Below the most commonly used types of tamper techniques are presented and ADDAX meter solutions for avoiding this tampering are described. The examples are presented for the single-phase meters. For the three-phase meters principles of tamper detection are practically the same.

[1] Relates only to the direct connected meters. For transformer connected meters tamper detection scheme is not used.

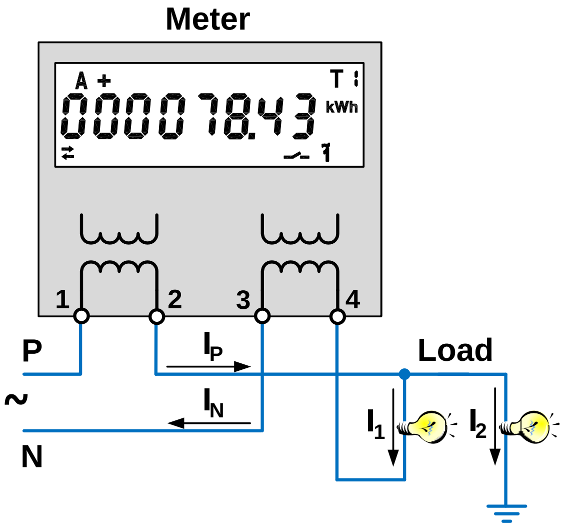
Tamper Detection:

1. Normal Phase & Neutral Connection

Connection Diagram	Description	Meter reaction	Display indication[1]
	Current, flowing through the phase wire is the same as coming out of the neutral wire (**$I_P=I_N$**). **$I_p=I_1+I_2$**	Meter operates in normal mode.	$\tilde{1}$ - phase presence (for single-phase meter). $\tilde{1}$ $\tilde{2}$ $\tilde{3}$ - phases presence (for three-phase meter).

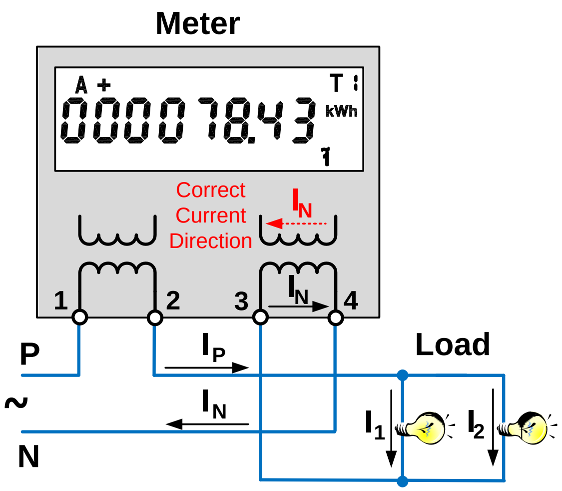
[1] Parameters and symbols to display depend on the configuration, set previously in the meter. Maximum number of parameters to display - 16. Symbols are displayed as respective event takes place. For more details about the meter parameters and symbols on the display apply to annexes A1, A2 and A3.

2. Partial Earth Fault

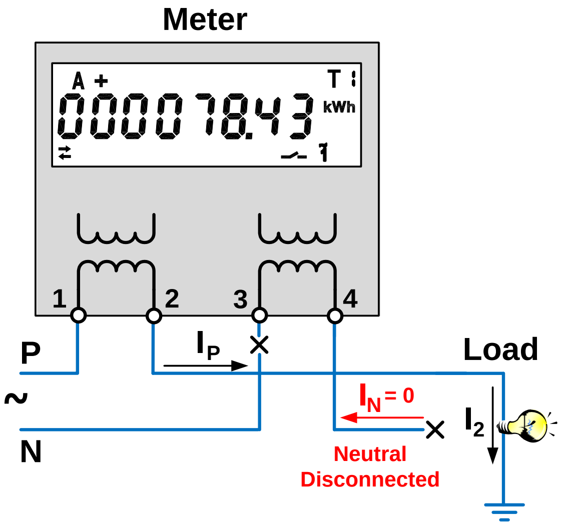
Connection Diagram	Description	Meter reaction	Display indication
	An earth fault takes place when some or all loads are connected to another ground potential and not the neutral wire. At the figure a partial earth fault is illustrated. One of the loads is connected to the ground and therefore part of the return current ($\mathbf{I_2}$) does not flow through the meter. Thus, the current in the neutral wire ($\mathbf{I_N}$) is less than that in the phase wire ($\mathbf{I_P}$). $\mathbf{I_N < I_P}$ $\mathbf{I_{dif} = I_P - I_N}$ By analogy, if phase and neutral wires are swapped (see pt. 3) the current in phase wire is less than that in the neutral. $\mathbf{I_{Psw} < I_{Nsw}}$ $\mathbf{I_{difsw} = I_{Nsw} - I_{Psw}}$	To detect this event, the meter monitors the currents on both wires – phase and neutral, and compares them. The difference between neutral and phase currents is **differential current**, which can be used as an indicator of tampering attempts. If phase and neutral currents differ significantly and exceed a threshold set, the firmware uses the greater of two currents to determine the amount of energy to be billed and signals about differential current presence. Also the meter can switch consumer off with the help of breaking relay. Thresholds for differential current value and duration, as well as the action to switch the consumer off may be set in the meter configuration.	- phase presence; - differential current presence; - relay is disconnected (if the basic relay is configured to switch off, when the differential current exceeds the limit set, see annex A3).

3. Reverse Current

Phase & Neutral Wire Swapped

Connection Diagram	Description	Meter reaction	Display indication
	When phase or/and neutral wires are connected to the wrong inputs the current flows in the direction opposite to normal. In this case reverse current occurs. In the figure neutral wire connection is swapped. Therefore neutral current (**I_N**) is caused to flow in the reverse direction to the expected one.	Reverse current causes the wrong sign for active power readings. When any of the two currents has a sign opposite to the one expected the meter activates the reversed current indicator. But meter software always uses the absolute value of active power for driving the energy pulse and thus the direction of the current has no effect on energy calculation.	**1̃** - phase presence; **A +** - active energy in forward direction, import (if the meter is configured to control and display this parameter, see annex A3); **A −** - active energy in backward direction, export (when phase wired connection is swapped) (if the meter is configured to control and display this parameter, see annex A3).

4. Missing Neutral

<table>
<tr><th>Connection Diagram</th><th>Description</th><th>Meter reaction</th><th>Display indication</th></tr>
<tr>
<td>
</td>
<td>The missing neutral tampering condition takes place when the neutral is disconnected from the meter.

When the neutral is disconnected, there is no voltage input and therefore no output would be generated by the power supply.

However when the load is applied, there would be a valid input signal on the 1st current channel ($\mathbf{I_P}$) so power would be consumed.

Since the current in neutral is zero, so is the power.

$\mathbf{I=0}$

$\mathbf{P=U \times I=0}$</td>
<td>In the missing neutral mode the meter calculates the energy based on the active current input signal level.

Tampering algorithm assumes voltage, fixed at a known amplitude and phase, and continues to calculate the current power, based on the current root mean square (RMS) value. It adjusts the current RMS to produce the same power output when the voltage is at its nominal value.

This ensures that billing is continued during a missing neutral condition.

Since the current in neutral is zero and only phase current is present, differential current condition occurs (see pt.2).

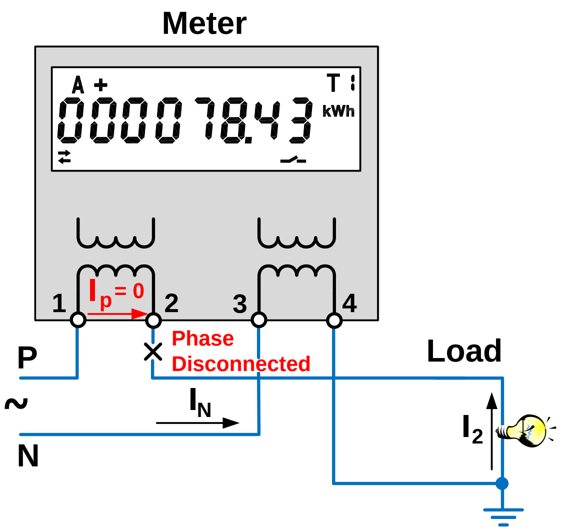
$\mathbf{I_N=0}$, $\mathbf{I_P>0}$ $\mathbf{=> I_{dif} = I_P - I_N > 0}$</td>
<td>1̃ - phase presence;

⇄ - differential current presence;

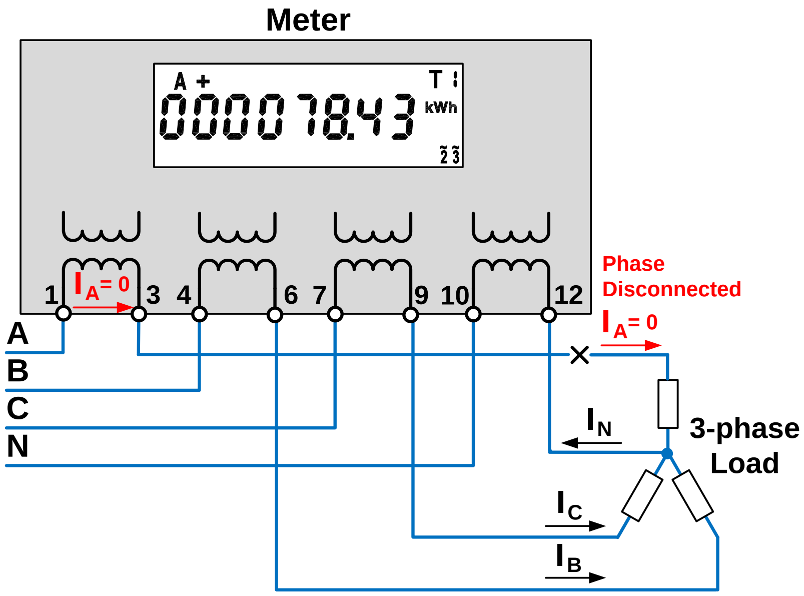
relay symbol - relay is disconnected (if the basic relay is configured to switch off, when the differential current exceeds the limit set, see annex A3).</td>
</tr>
</table>

5. Missing Potential

5.1 Single-Phase Meter

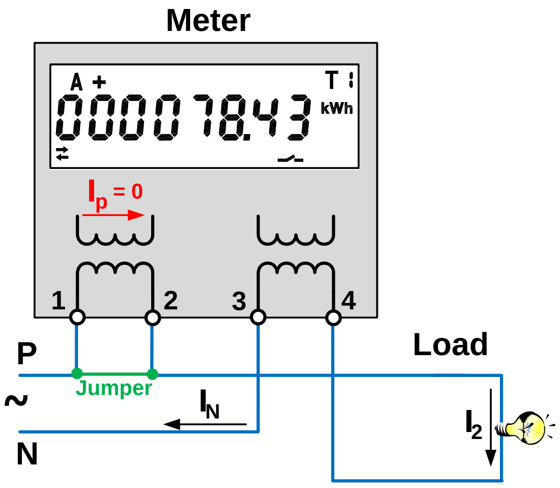
Connection Diagram	Description	Meter reaction	Display indication
	The missing potential tampering condition takes place when one of the phase wires is removed from the meter terminal. In this case phase current component (**I_P**) is equal to zero so meter does not record consumption on that phase. **I=0** **P=U×I=0**	Since the current in phase is zero and only neutral current is present, differential current condition occurs (see pt.2). **$I_P=0$, $I_N>0$ => $I_{dif} = I_N - I_P > 0$** As the 1st measuring channel (phase) is used in energy calculation and phase current is zero, no energy is accumulated. The meter signals about differential current presence and can switch consumer off with the help of breaking relay.	No $\tilde{1}$ sign – no phase; ⇄ - differential current presence; relay symbol - relay is disconnected (if the basic relay is configured to switch off, when the differential current exceeds the limit set, see annex A3).

5.2 Three-Phase Meter

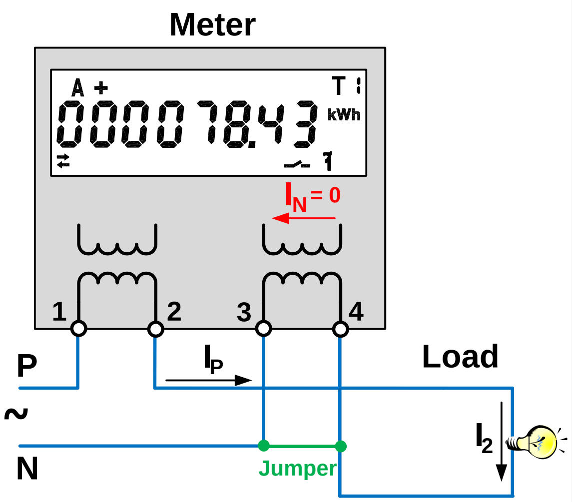
Connection Diagram	Description	Meter reaction	Display indication
	For the three-phase meter the missing potential tampering condition takes place when one or two of the phases are not connected to the meter terminal. In this case current through the missing phase, for example phase **A** at the picture (**I_A**), is equal to zero so meter does not record consumption on that phase. **I=0** **P=U×I=0**	Since the current in phase **A** is zero, neutral current is equal to the geometrical sum of the currents of the rest phases. **I_A=0** **I_N=I_A+I_B** For the three-phase meter this results in recording less total energy consumption.	$\tilde{1}\ \tilde{2}\ \tilde{3}$ - absence of symbol indicates phase voltage absence (for example, $\tilde{2}\ \tilde{3}$ for the illustrated case).

6. Bypassing the Meter

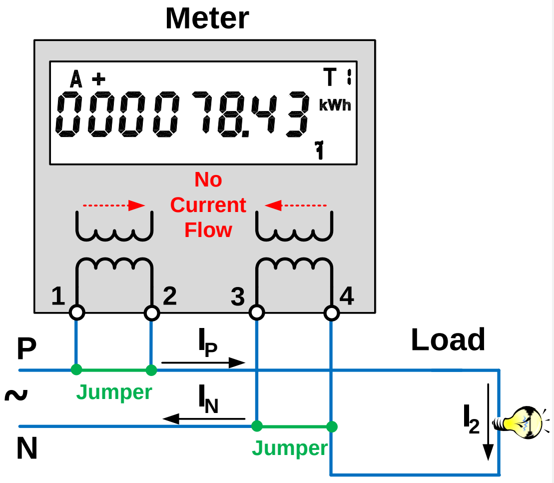
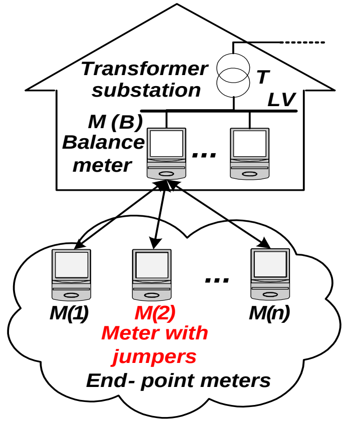
6.1 Jumper in the Phase Circuit

Connection Diagram	Description	Meter reaction	Display indication
	Bypassing takes place when jumpers are put at the meter terminals to bypass the meter measuring part. In this case meter may not register energy consumption.	If the jumper is set in the 1st measuring channel, differential current condition occurs (see pt.2). $I_P=0$, $I_N>0$ => $I_{dif} = I_N - I_P > 0$ As the 1st measuring channel (phase) is used in energy calculation and phase current is zero, no energy is accumulated. The meter signals about differential current presence and can switch consumer off with the help of breaking relay.	No $\tilde{1}$ sign – no phase; ⇄ - differential current presence; - relay is disconnected (if the basic relay is configured to switch off, when the differential current exceeds the limit set, see annex A3).

6.2 Jumper in the Neutral Circuit

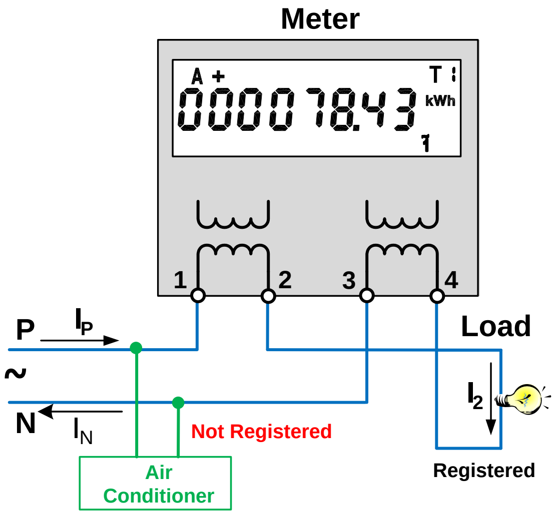
Connection Diagram	Description	Meter reaction	Display indication
	Bypassing takes place when jumpers are put at the meter terminals to bypass the meter measuring part and not to register the energy consumption.	If the jumper is set in the 2st measuring channel, the same differential current condition occurs (see pt.2). $I_N=0$, $I_P>0$ => $I_{dif} = I_P - I_N > 0$ The meter calculates the energy based on the phase current. Also it signals about differential current presence and can switch consumer off with the help of breaking relay.	- phase presence; - differential current presence; - relay is disconnected (if the basic relay is configured to switch off, when the differential current exceeds the limit set, see annex A3).

6.3 Jumper in Both Phase and Neutral Circuits

Connection Diagram	Description	Meter reaction	Display indication
	If jumpers are put in both phase and neutral circuits no current flows through the meter measuring channels and thus no consumption is detected.	To detect this kind of tamper **imbalance control principle**[1] may be used. To control the imbalance a balance group should be created, consisting of the end-point meters and balance meter, installed at the group input (at transformer substation).  Balance meter readings should be equal to the sum of end-point meters' readings. $\mathbf{W_B=W_1+W_2+...+W_n}$. If we consider that a meter, for example meter **M(2)** at the scheme, is connected with jumpers, than $\mathbf{W_B<W_1+W_2+...+W_n}$. This may testify about electric energy losses, caused by the fraud attempts.	No $\tilde{1}$ sign – no phase.

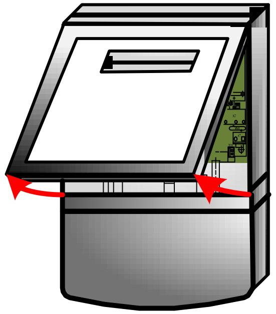
[1] For more details about imbalance control principle apply to annex A4.

7. Double Feeding the Meter

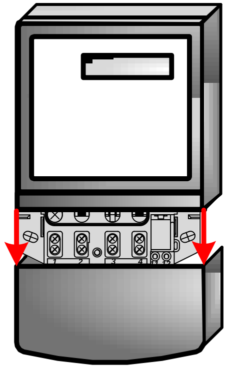
Connection Diagram	Description	Meter reaction	Display indication
	To bypass the meter additional feeding is connected directly to the line so that the consumption for additional feeding in not registered.	To detect this kind of tamper imbalance control principle may be used (see pt. 6.3).	1̃ - phase presence.

Meter Manipulated Detection:

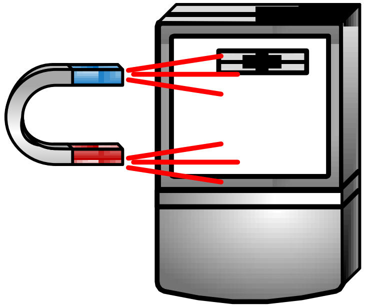
1. Meter Case Opening

Illustration	Description	Meter reaction	Display indication
	Attempts to open the meter case are made to change the meter structure and manipulate the meter.	To detect this kind of tamper the meter case opening sensor is provided. When respective event takes place an alarm is sent to the Master Station and a proper symbol occurs on the meter display. The sensor operates even when the power is off due to the meter backup power supply.	- meter cover is removed.

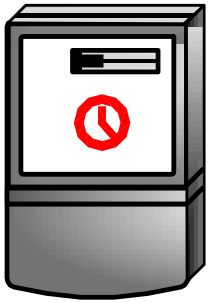
2. Terminal Box Cover Opening

Illustration	Description	Meter reaction	Display indication
	Attempts to open the meter terminal box cover are made to change the meter connection to create tamper conditions, mentioned above in the previous section.	To detect this kind of tamper the terminal box cover opening sensor is provided. When respective event takes place an alarm is sent to the Master Station and a proper symbol occurs on the meter display. The sensor operates even when the power is off due to the meter backup power supply.	- terminal box cover is removed.

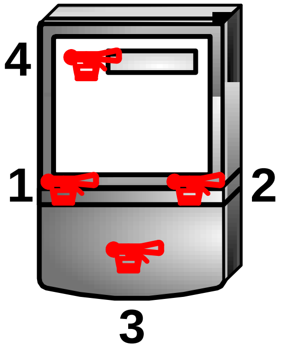
3. Strong External Magnetic Field

Illustration	Description	Meter reaction	Display indication
	The meters use magnetic material in voltage and current measurement circuits and thus are affected by abnormal external magnetic influences, that in their turn affect proper functioning of the meter. For example, a strong magnet may be used to change the magnitude of current. This in its turn can introduce errors in the measurement and results in less billing.	To detect this kind of tamper the magnetic field sensor is provided in the meter. The sensor measures external magnetic field starting with 1mT. Field less than 200 mT does not influence the meter and normal meter operation is guaranteed. When external field is 200 mT and greater, meter normal operation is not guaranteed. In this case respective alarm message is sent to the Master Station.	No symbol available.

4. Tariffs Manipulation

Illustration	Description	Meter reaction	Display indication
	To support TOU tariff metering RTC is provided in the meter. Attempts to tamper the clock or manipulate the time to "trick" the system and lowered tariff metering may be done. For example, if PM is changed to AM, meter firmware calculates less due to non-peak load during that time.	During meter operation as a part of the metering system, constant external synchronization of the meter clock with the system clock via data transfer network is ensured. If deviation between the meter and system clocks exceeds the allowed value respective flag is set in the Master Station and a proper symbol occurs on the meter display. The allowed daily clock deviation is set in the meter configuration. No date and time setting is available. Backup supply ensures the clock operation when the power is off.	 - time synchronization error.

5. Unauthorized Access

Illustration	Description	Meter reaction	Display indication
	Attempts to open the meter terminal box cover or meter cover are done to create tamper conditions and manipulate the meter as it is described above. To decrease energy billings the same meter reset button may be accessed.	To prevent the meter from unauthorized access special protective seals are provided in the meter structure. Manufacturer (**1**) and metrological service (**2**) seals are fixed at the meter cover screws and protect it from unauthorized opening. Seal of power authority (**3**) is fixed at the meter terminal box screw and protects the meter from unauthorized connection. Reset button seal (**4**) prevents unauthorized access to reset meter readings to zero. All the seals are fixed on the meter front side and are easily visible to a meter reader or inspector. Once broken, these seals cannot be glued or repaired.	- meter cover is removed, which means that seals **1** and **2** are broken; - terminal box cover is removed, which means that when seal **3** is broken.

Annex 1. References

1. Extra Series Meters. User Manual.
2. Lite Series Meters. User Manual.
3. How to Configure Lite Meters in ADDAX Framework. Instruction.
4. Imbalance Control. General Description.