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DEVELOPMENT OF MECHANISM FOR METER TAMPER DETECTIONS AND COUNTER MEASURES

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Abstract— **In developing countries like Nigeria, energy theft is one of the major causes of loss of revenue to power utility companies. Particularly, there is high rate of these thefts at the distribution end due to so many illegal connections at the consumer ends. Unfortunately, there is no systematic method of detecting and controlling these thefts, even with the deployment of smart meter technologies across the country. Consequently, in this paper, approaches for the detection of conventional meter tampering and the counter measures to ensure appropriate meter reading in the face of the tampering are developed. Major forms of electricity theft considered in this paper include: reverse tamper, earth tamper, cover open tamper, magnetic tamper, single wire tamper, shorting the phase line tamper and meter bypass tamper. For each of the energy theft approaches discussed, relevant analytical expressions are provided for the detection of the energy theft and also for the counter measure. Finally, a flowchart is developed that enable the system to detect energy theft, classify them and transmit the metering data to the service centre. Some simulations were conducted in MATLAB software to show the current and voltage waveforms, the waveforms for the power and energy consumed by the load, as well as the waveforms for the power and energy recorded by the energy meter. The simulation results clearly showed those occasions where the meter tampering produced metered power that are different from the actual consumed power. In such cases, the system is supposed to use the flowchart provided in this paper to alert the relevant unit and also take the right step to correct the meter reading to the actually consumed energy.**

Keyword: Energy Theft, Smart Meter, Reverse Tamper, Earth Tamper, Cover Open Tamper, Magnetic Tamper, Conventional Meter , Single Wire Tamper, Shorting The Phase Line Tamper And Meter Bypass Tamper

I. INTRODUCTION

Traditionally, energy consumed by customers is mostly gotten by manually taking periodic readings from the display of electro-mechanical meters installed at their premises [1,2,3]. As this method is labour intensive, electronically read measurements that can be transmitted through a communication media are preferred. This can be achieved by different methods of retrofitting on to existing meters. Accordingly, nowadays, the use of smart metering technologies is on the increase in developing countries like Nigeria [4,5,6,7].

Smart metering generally involves the installation of an intelligent meter at customers' end and the regular automatic reading, processing and feedback of consumption data to the customer [8,9,10,11,12,13]. Notably, smart meters are indispensable enabler in a context of smart metering which deploy advanced information and communication technology to control the electrical consumption [14,15]. However, energy theft is a common phenomenon in developing countries which do persist even with the adoption of smart meter technologies. Generally, energy theft is known to be the main cause of loss of revenue to the power utility company.

In Nigerian, there is perennial shortage of power supply from the national grid. As such, many energy consumers are relying on alternative such as diesel generators and solar power system [16,17,18]. However, in Nigeria, the epileptic power supply that comes from the national grid suffers high rate of energy thefts at the distribution end due to so many illegal connections. Unfortunately, there is no systematic method of detecting and controlling these thefts. The existing home meters in Nigeria lacks the ability to detect this electricity tampers and the conventional meters being deployed need to be enhanced to detect and counter the various energy theft strategies [19]. Consequently, in this paper, measure for detecting and countering energy theft in home by conventional meter tampering is developed. The system will be able to detect energy theft, classify them and transmit the metering data to the service centre as well as perform appropriate billing computations even in the face of the energy theft.

II METHODOLOGY

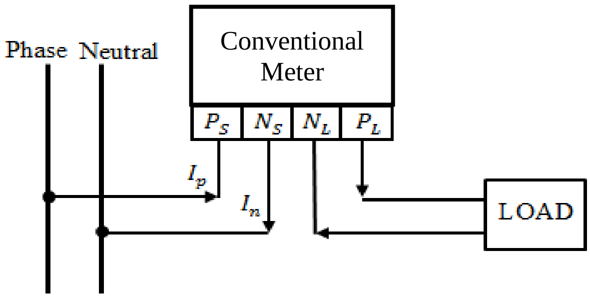
In this paper different energy theft cases for a single phase connection are identified and the appropriate counter measure for each case is proffered. The energy theft cases considered includes: reverse tamper, earth tamper, cover open tamper, magnetic tamper, single wire tamper, shorting the phase line tamper and meter bypass tamper. Relevant analytical expressions are provided for the detection of each energy theft case as well as for the counter measure. Finally, a flowchart is developed that enable the system to detect energy theft, classify them and transmit the metering data to the service centre. Some simulations are conducted in MATLAB software to show the current and voltage waveforms, the waveforms for the power and energy consumed by the load, as well as the waveforms for the power and energy recorded by the energy meter.

A. NORMAL CONNECTION OF THE CONVENTIONAL METER WITHOUT ANY TEMPER

The connection for normal operation of the conventional meter without any temper is shown in Figure 1. The relevant power equations for the normal operation of the meter in the case of single phase and three phase connections are show as follows:

Single phase: $$P = I_p V_p \quad (1)$$

Three phase: $$P = \sqrt{3} I_L V_L \quad (2)$$



B. REVERSE TAMPER CONNECTION OF THE CONVENTIONAL METER

In the case of reverse tamper connection of the conventional meter (Figure 2) reverse current occurs in the conventional meter. Specifically, reverse current occurs when the phase source is connected to the phase load terminal of the conventional meter and vice versa, thus causing current to flow in the opposite direction in the conventional meter. The relevant power equation for the reverse tamper connection of the conventional meter in the case of single phase is given as :

Power Equations: $\mathrm{P} = -\mathrm{I_p V_p}$ (3)

Notably, the reverse current that flow through the meter causes the meter to read reverse energy which take off the kWh reading from total reading. Hence, the reverse tamper is detected by checking the direction of the current.

In order to counter the effect of the reverse tamper connection of the conventional meter, the absolute value of the active power is used hence the reverse current has no effect on the energy calculation or accurate billing. In the case of single phase, the power equation for the counter measure against the reverse tamper connection of the conventional meter is given as:

Power Equations: $P = |I_p \times V_p|$ (4)

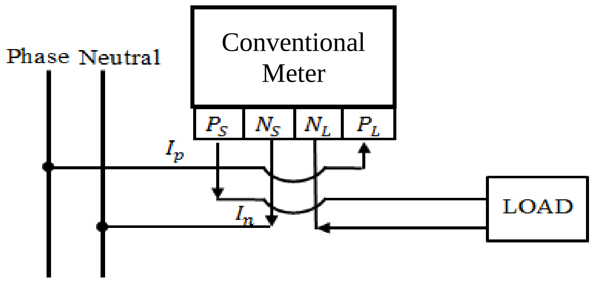


Figure 2: The connection of the conventional meter with reverse temper

C. EARTH TAMPER CONNECTION OF THE CONVENTIONAL METER

In the case of the earth tamper connection of the conventional meter an earth fault occurs. Specifically, an earth fault simply means that some of the load has been connected to another ground potential and not the neutral wire; that means, the current going through the phase wire is not the same as the one coming out of the neutral wire.

There are two types of earth tamper, namely partial and full earth condition. In partial earth condition (Figure 3), one of the loads is connected to earth and the other is returned back to neutral of the meter. In full earth condition (Figure 4), the total load is earthed. In both cases the current in the neutral wire is less than that in the phase wire. Generally, the earth tamper causes lower current than is consumed to flow through the meter, hence causing the meter to read less kWh.

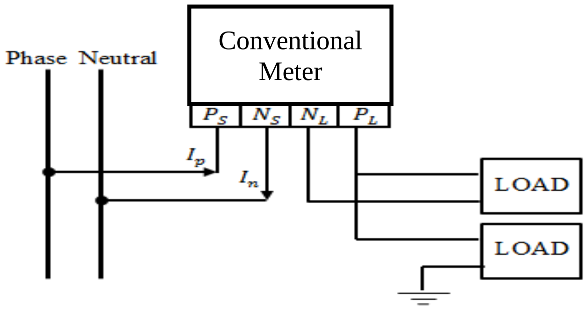


Figure 3: The connection of the conventional meter with partial earth temper

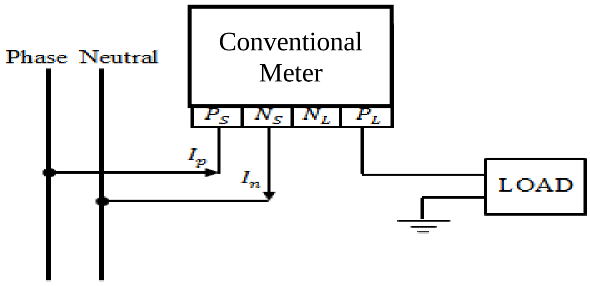


Figure 4: The connection of the conventional meter with total earth temper

In order to detect and counter the effect of the earth tamper connection of the conventional meter, the meter monitors the currents in both the phase wire and the neutral wire and the compares them. If the currents in the two wires differ significantly, the meter uses the larger of the two currents to determine the energy consume energy. In the case of single phase, the power equation for the counter measure against the earth tamper connection of the conventional meter is given as:

Power Equations: $$P = \begin{cases} \mathrm{I_p V_p}, & if\ I_p > I_n \\ \mathrm{I_n V_p}, & if\ I_p < I_n \end{cases} \quad (5)$$

D. MAGNETIC TAMPER OF THE CONVENTIONAL METER

Electromechanical meters use magnetic material in voltage and current measurement circuits, hence, the components of such meters are affected by abnormal external magnetic influences that affect the proper functioning of the meter. In the case of magnetic tamper of the conventional meter an external magnet is brought to the vicinity of the meter to affect the meter operations and readings. Specifically, when an external magnet is brought to an energy meter (induction type), the external magnetic field attracts the Aluminium disc and cause its speed to reduce. Since power (P) measured is proportional to the speed (n) of the disc, the power is as well reduced. Hence, the consumer consumes more kWh than is recorded by the meter.

One way to avoid magnetic tamper is by having magnet sensors to detect the presence of abnormal magnetic fields around the meter. Alternative approach to circumvent magnetic tamper is by shielding the sensor thereby suppressing the magnetic field effect. The magnetic field effect can also be suppressed by increasing the gap that exist between the magnet and the sensor. In any case, such counter measures become useless if the consumer remove or bypass the magnetic sensors/shielding device. As such a more robust counter measure against magnetic tamper is to use the rms values of the current and the voltage to compute the power consumed by the consumer as follows:

$$P = I_{rms}V_{rms}. \tag{6}$$

Notably, without external magnetic influence, the waveform of ac current is shown in Figure 5, and the rms value of current is given as

$$I_{rms} = \frac{I_m}{\sqrt{2}} \tag{7}$$

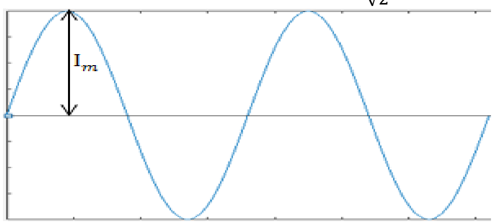
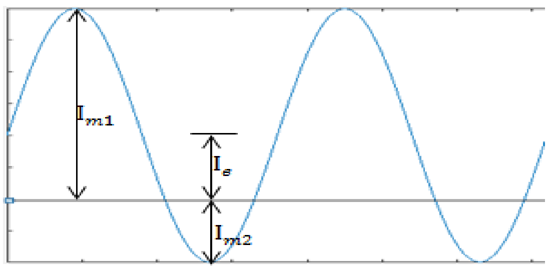


Figure 5: The waveform of ac supply without external magnetic influence

On the other hand, with the external magnetic influence, the waveform of the ac current is pushed upward as shown in Figure 6 and the rms value of current is given as:

$$I_{rms} = \frac{\sqrt{I_{m1}^2 + I_{m2}^2}}{2} \tag{8}$$

Where $I_{m1} \neq I_{m2}$.



(b)

Figure 6: The waveform of ac supply with external magnetic influence

Comparing Figure 5 and Figure 6,

$$I_{m1} + I_{m2} = 2I_m \tag{9}$$

$$I_{m1}^2 + I_{m2}^2 = 4I_m^2 - 2I_{m1}I_{m2} \tag{10}$$

Substituting equation (10) into (8) gives;

$$I_{rms} = \frac{\sqrt{4I_m^2 - 2I_{m1}I_{m2}}}{2} \tag{11}$$

$$I_{rms} = \sqrt{I_m^2 - \frac{I_{m1}I_{m2}}{2}} \tag{12}$$

Comparing equations (7) and (12) gives,

$$\sqrt{I_m^2 - \frac{I_{m1}I_{m2}}{2}} \geq \sqrt{\frac{I_m^2}{2}} \tag{13}$$

Thus, the rms value of the current under external influence is actually more than that without external influence. Hence, the recorded energy by the meter will be more than what the consumer consumes.

E. SHORTING THE PHASE LINE TAMPER OF THE CONVENTIONAL METER

In this type of tamper, the phase line is shorted (Figure 7), thus making the meter to measure zero phase current. Phase line is shorted under this condition, the power recorded by the meter is zero i.e. $P = 0 \times V_p = 0$.

In order to overcome shorting the phase line tamper, the meter compares the values of phase current and neutral current. If the phase current differs significantly from the neutral current, then the meter makes use of the larger of the two currents to determine the consumed energy.

$$\textbf{Power Equations: } P = \begin{cases} I_p V_p, & if\ I_p > I_n \\ I_n V_p, & if\ I_p < I_n \end{cases} \tag{14}$$

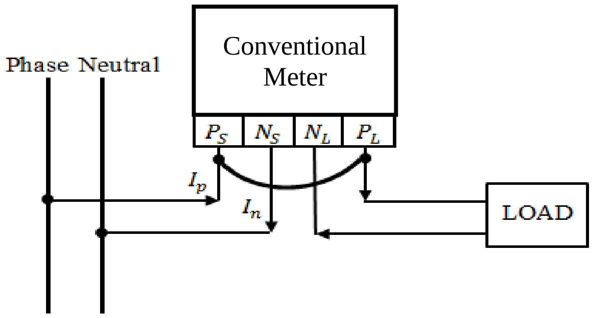


Figure 7: The connection of the conventional meter with shorting the Phase Line temper

F. METER BYPASS TAMPER

Energy meters can be bypassed in many ways. The most common way is by putting a jumper in the meter terminal (Figure 8) such that connection is bypassed and the energy consumption is not registered.

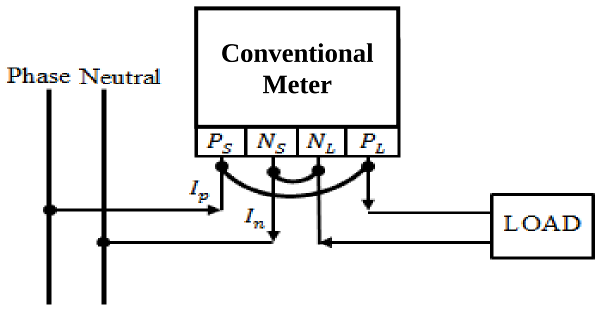


Figure 8: The connection of the conventional meter with meter bypass temper

Meter bypass tamper can easily be detected by splitting the conventional meter into two units – measurement and control unit and customer interface unit. While the measurement and control unit does the recording and control, the customer interface unit provides an interface for the consumer to carry out various services.

G. COVER OPEN TAMPER

This type occurs when the meter casing is open for the purpose of tampering which can be by changing the value of the burden resistance to a lower value so that it measures less current or by removing the RTC battery.

The counter measure is that as soon as the meter casing is opened, the input on the tamper pin will change from 0 to 1. Thus;

$$S = \begin{cases} 1, & if\ Cover\ is\ opened \\ 0, & if\ Cover\ is\ closed \end{cases} \quad (15)$$

Anti-tamper switches are placed on the casing of the meter to trigger a tamper and record the cover open tamper with date and time, when the casing is opened. In any case, such counter measure is not satisfactory because the consumer will still be connected to power line, irrespective of the fact he might have succeeded in tampering the meter to record less energy than consumed. It is recommended that in addition the existing counter measure; the consumer should be disconnected automatically from the utility pole.

H. SINGLE WIRE TAMPER OF THE CONVENTIONAL METER

The single wire tampering condition occurs when the neutral wire is disconnected from the power meter, as shown in Figure 9.

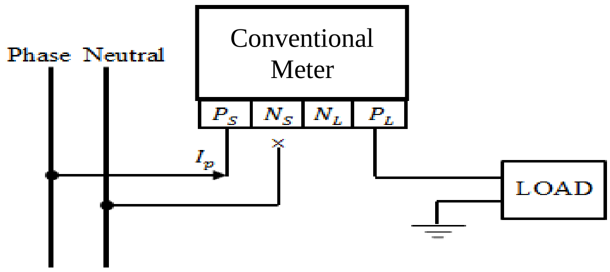


Figure 9: The connection of the conventional meter with single wire temper

Specifically, when the neutral is disconnected, there is no voltage; hence there is no power recorded, hence; $P = I_p \times 0 = 0$. There is currently no counter measure except for monitoring by utility personnel. In order to handle this type of tampering, the power is calculated using a fixed value of voltage i.e. $P = I_p \times 240$

III. SIMULATION AND RESULTS

The algorithm for the various meter tamper and the corresponding counter measures is given in Figure 10. The different types of single phase meter tampers discussed in this paper were modelled and simulated with 2019a version of MATLAB/Simulink software. The waveforms associated with the various tampers are presented in Figure 11 to Figure 16. With the steps outlined in the flowchart, the system will be able to detect energy theft, classify it and transmit the metering data to the service centre as well as perform appropriate billing computations even in the face of the energy theft.

Figure 11 shows a scenario where the meter is not tampered. As can be seen, the line (phase) and neutral currents are the same, and the phase voltage is normal. The energy and power consumed by the load is the same as the recorded value. This information shows that there is no energy theft.

It can be quickly observed in Figure 12 that the magnitudes of the line and neutral currents are equal, but they are actually 180^o out of phase. This is clear in the power and energy waveforms which show a negative recorded power and a decreasing recorded energy. This indicates that the supply line is connected to the load terminal of the meter, while the load is connected to the supply terminal.

In Figure 13, it is seen that the energy and power recorded by the meter are zero as against the actual consumed power. This can be traced to a zero value of the neutral current even when the line current is non-zero. This shows that the load is disconnected from the neutral and connected to earth.

The case in Figure 14 is similar to that of figure 3, except for the fact that some loads are still connected to the neutral line while some are connected to earth. This is seen in a lower neutral current than the line current, which translates to a lower power and energy when compared to the consumed.

As can be seen in Figure 15, the phase voltage and neutral current are zero while the line current is non-zero. The only possible explanation to this is a disconnection of the neutral from the supply terminal of the meter. Under this condition, zero power and energy are recorded by the meter.

In Figure 16, the line current is zero, while the neutral current and phase voltage are non-zero. This shows that the load is actually connected, but the line current is not seen by the meter, meaning the two meter's line terminals are shorted leading to zero current flowing into the meter.

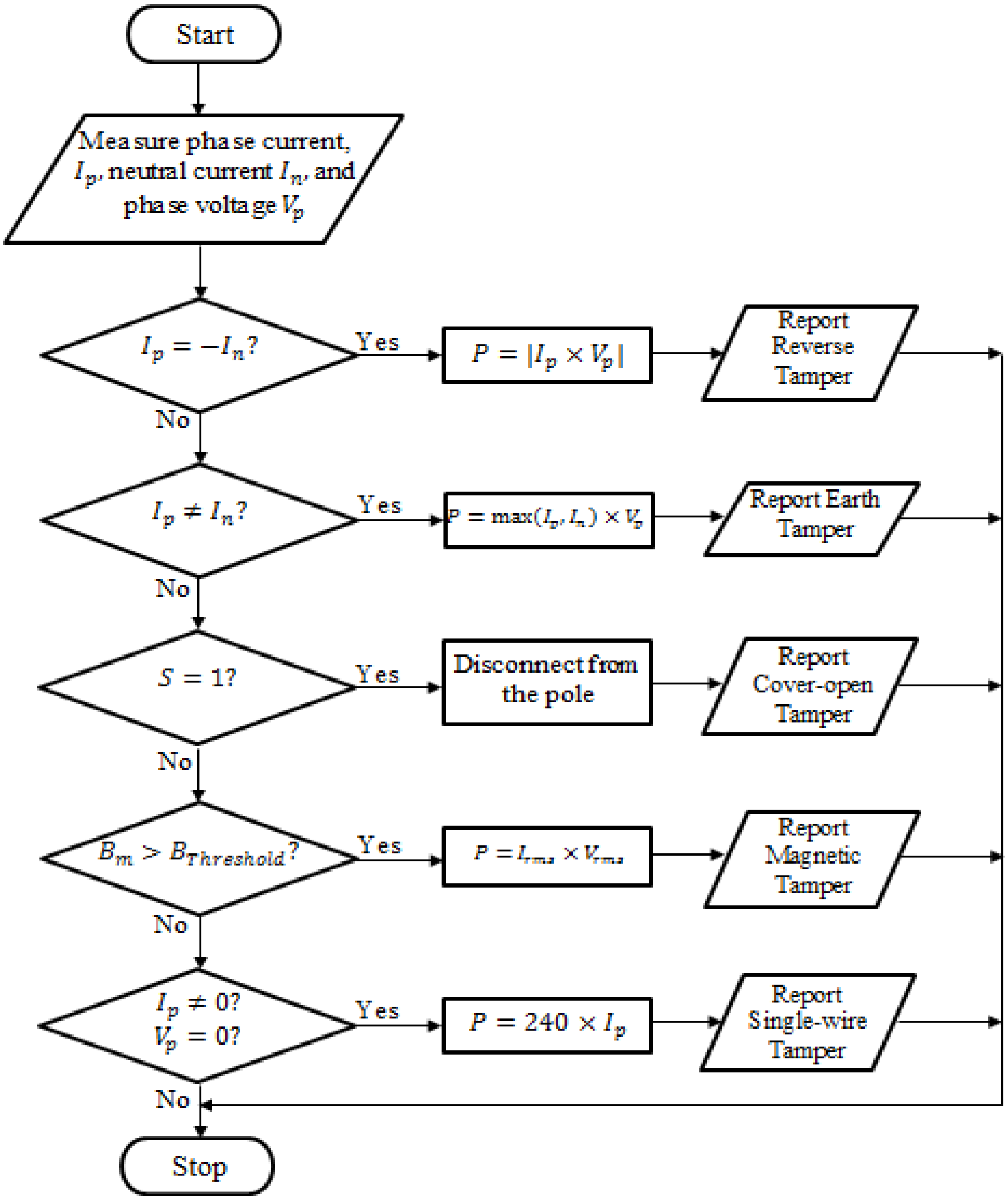
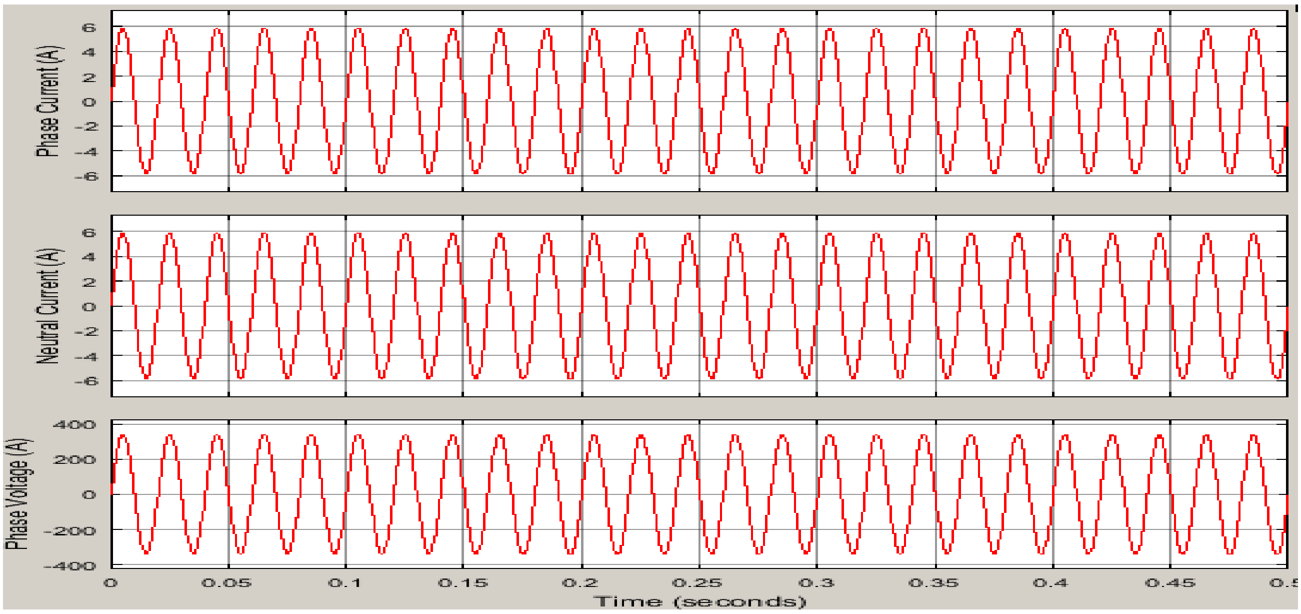
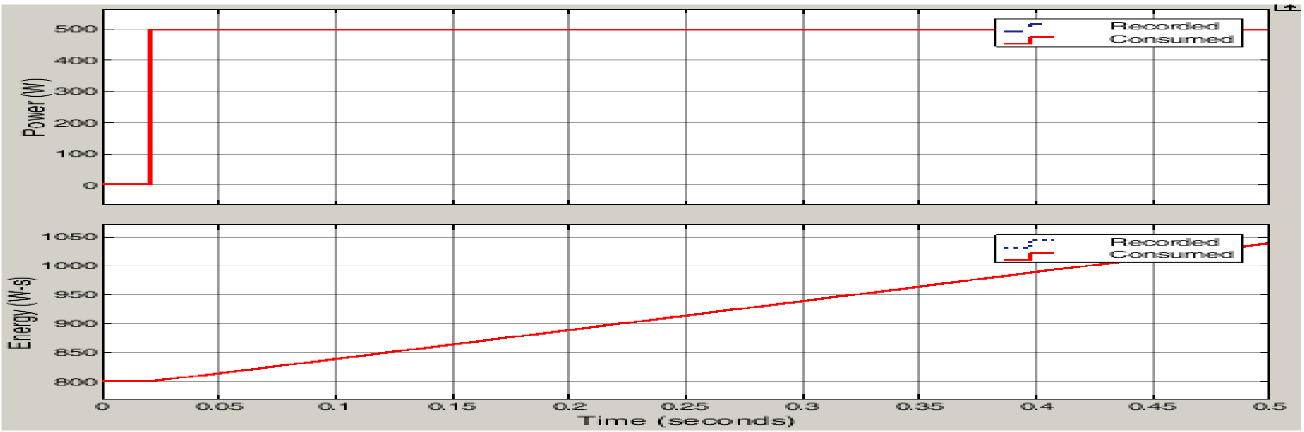


Figure 10: The algorithm for the various meter tamper and the corresponding counter measures

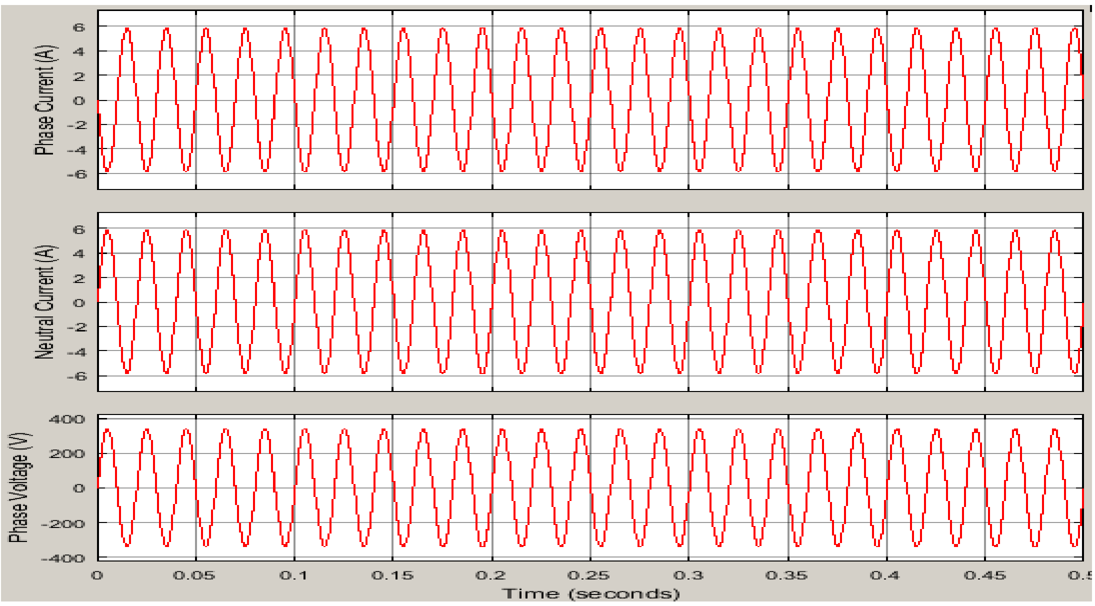


(a) Current and voltage waveforms

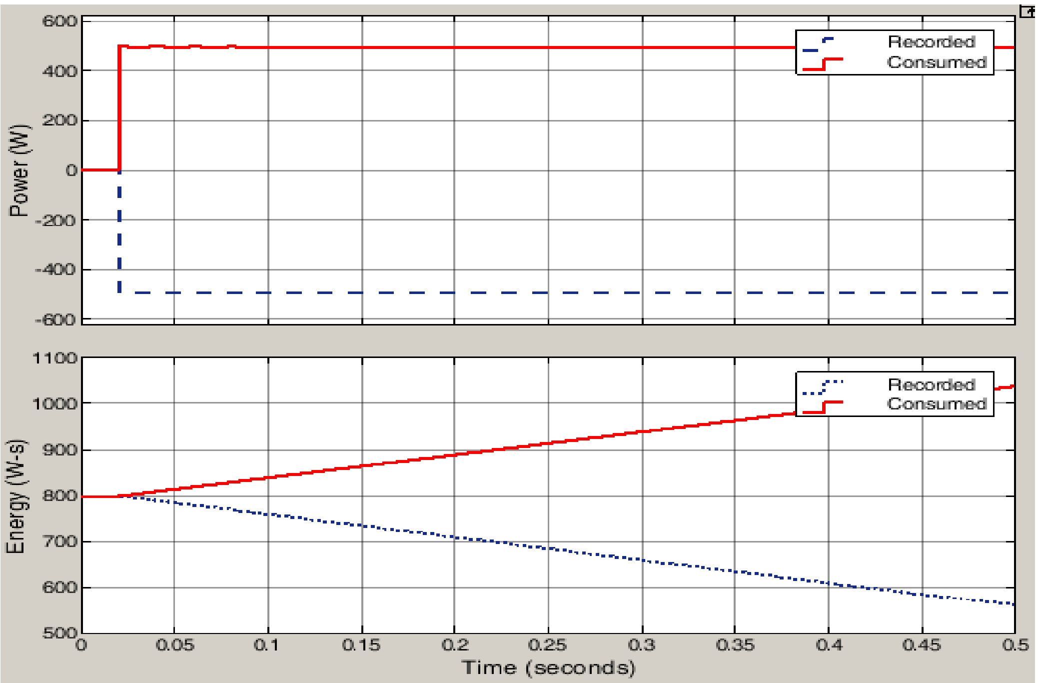


(b) Power and energy waveforms

Figure 11: Normal Connection for a single phase Conventional Metering

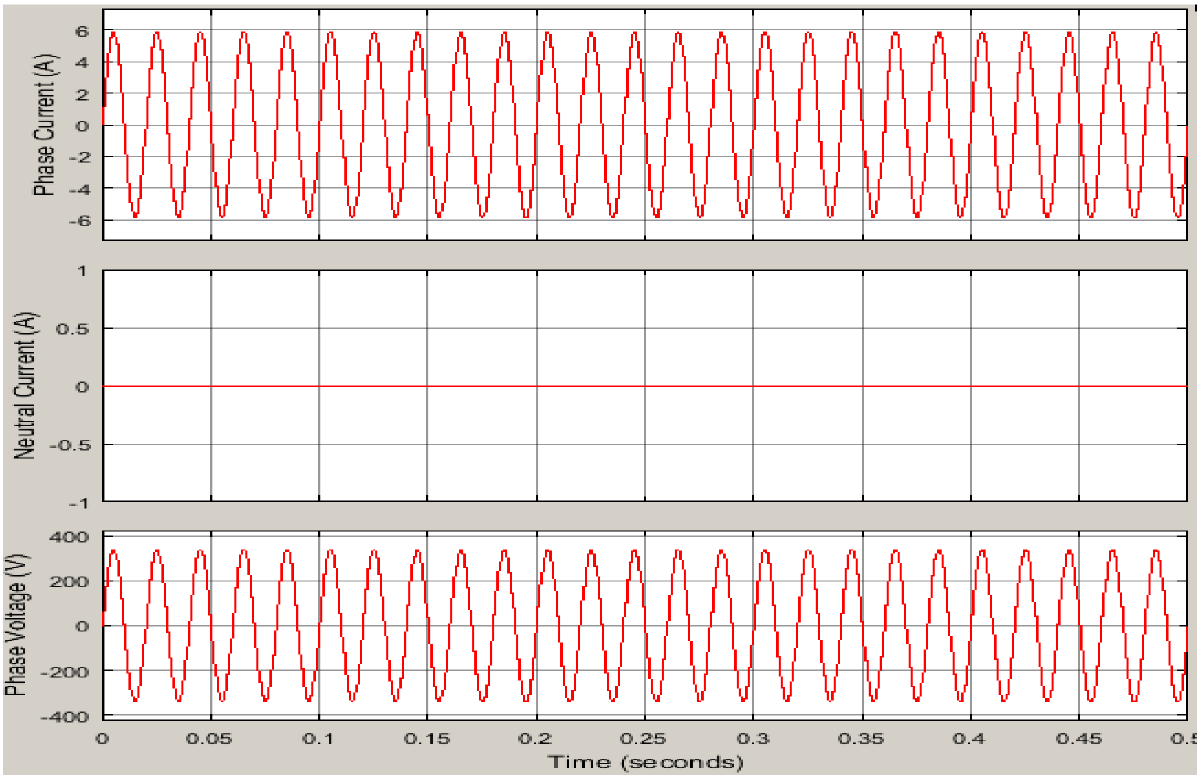


(a) Current and voltage waveforms

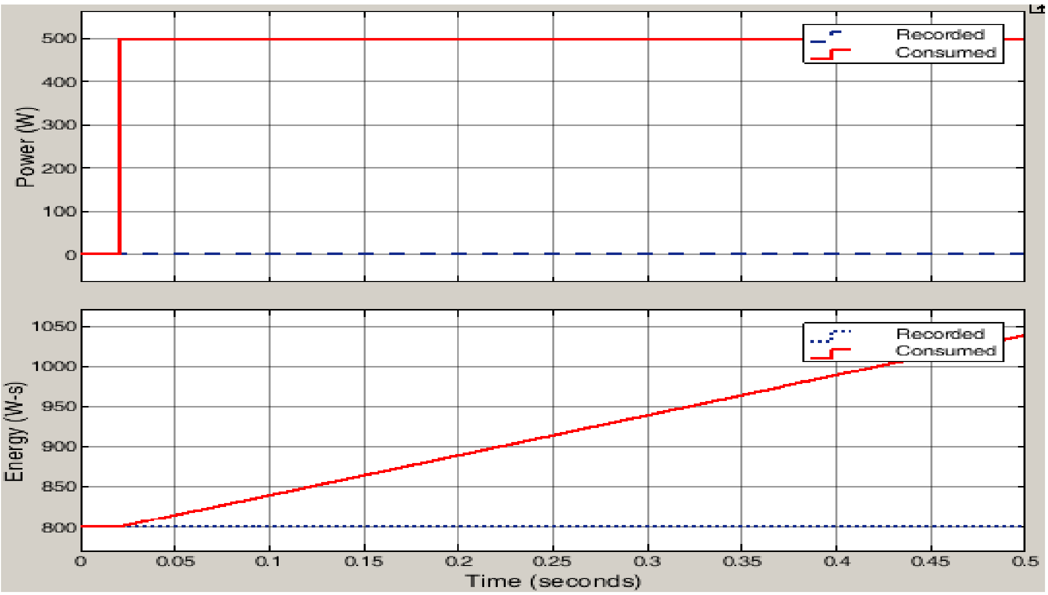


(b) Power and energy waveforms

Figure 12: Single Phase Conventional Metering: Reverse tamper

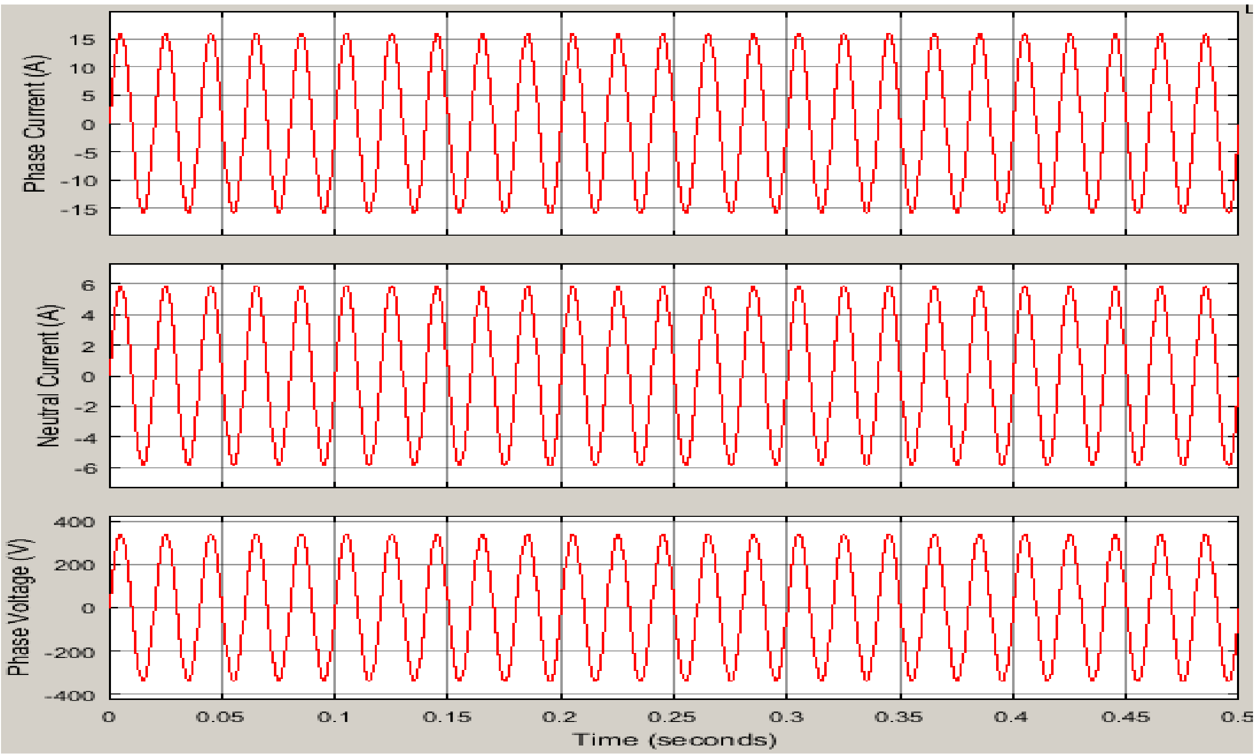


(a) Current and voltage waveforms

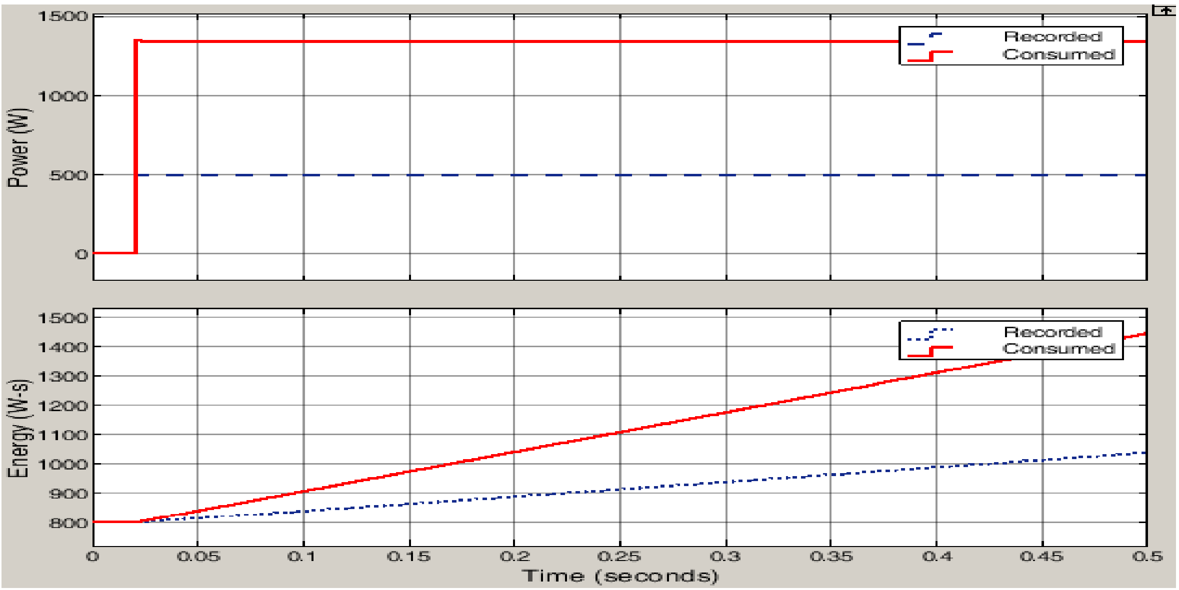


(b) Power and energy waveforms

Figure 13: Single Phase Conventional Metering: Total earth tamper

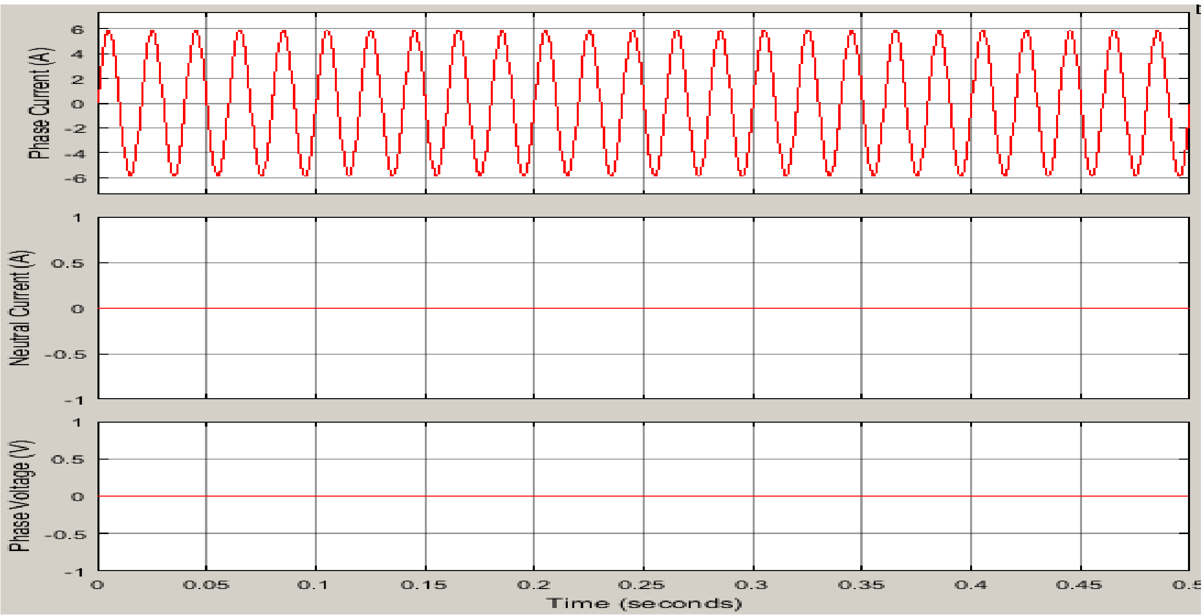


(a) Current and voltage waveforms

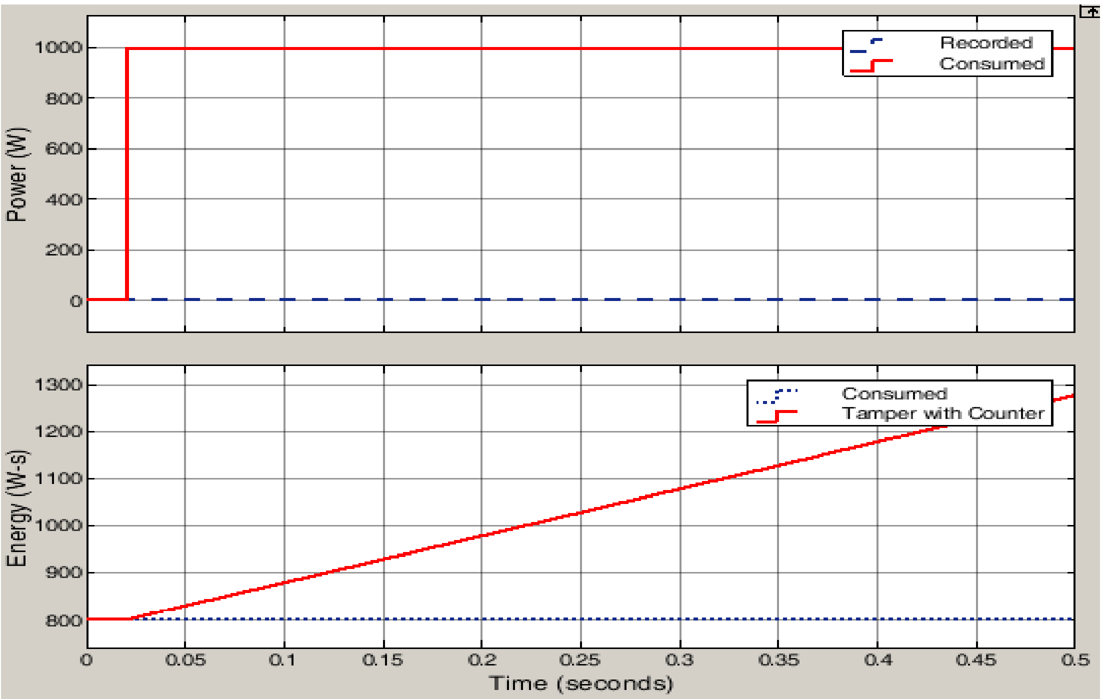


(b) Power and energy waveforms

Figure 14: Single Phase Conventional Metering: Partial earth tamper

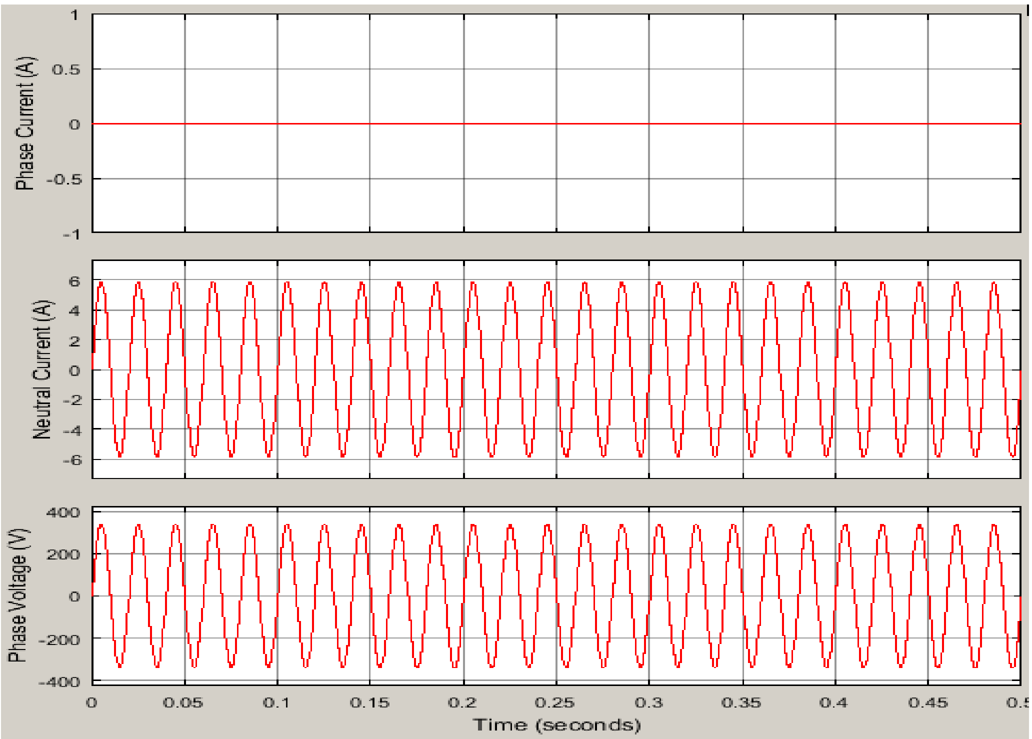


(a) Current and voltage waveforms

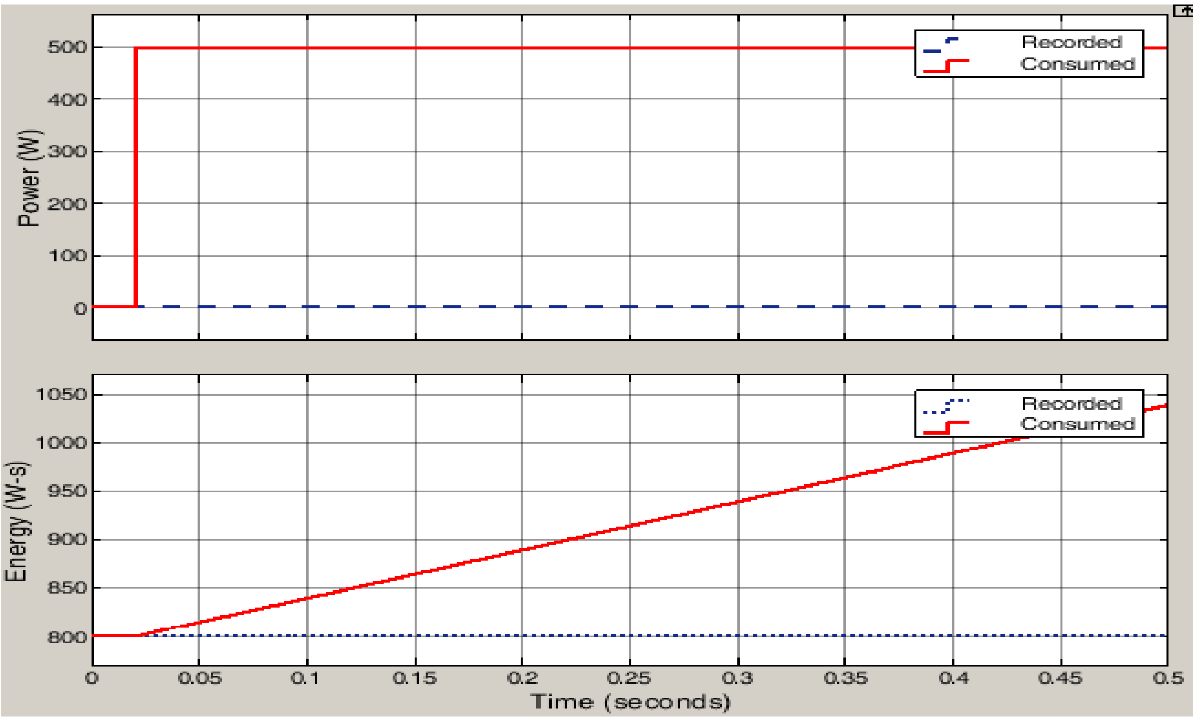


(b) Power and energy waveforms

Figure 5: Single Phase Conventional Metering: Single wire tamper



(a) Current and voltage waveforms



(b) Power and energy waveforms

Figure 16: Single Phase Conventional Metering: Shorting the phase line tamper

4 CONCLUSION

In this paper, the issue of energy theft due to conventional meter tamper is presented. Specifically, different types of single phase meter tampers are discussed and relevant mathematical expression are presented for each of the meter tamper approaches. The various meter tamper approaches considered in this paper includes: reverse tamper, earth tamper, cover open tamper, magnetic tamper, single wire tamper, shorting the phase line tamper and meter bypass tamper. Based on the analytical expressions, simulations were conducted in MATLAB software to show the current and voltage waveforms, the waveforms for the power and energy consumed by the load, as well as the waveforms for the power and energy recorded by the energy meter. Furthermore, flowchart was developed that can enable the enable the conventional metering system to detect energy theft, classify them and transmit the metering data to the service centre. In all, it is believed that the ideas presented in this paper will enable utility companies to minimise the losses they incur due to meter tampering.

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