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Detection And Counter Measures For Short-Circuiting 3-Phases To 1-Phase Tamper And Exploiting Unbalanced Line Tamper

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***Abstract*— In this paper, detection and counter measures for short-circuiting 3-phases to 1-phase tamper and exploiting unbalanced line tamper is studied. Circuit diagrams are used to describe and analytically model each of the two tamper scenarios considered. The detection and counter measure approaches are also presented in terms of the circuit diagrams and analytical expressions. Eventually, the detection and counter measure approaches are modelled and simulated using MATLAB/Simulink version 2019a. The simulation showed that in the short-circuiting 3-phases to 1-phase tamper the three current signals are in phase, meaning that all the three line inputs to the meter is of the same phase. This situation results in zero power and energy by the meter. However, with the introduction of the counter measure developed in this paper, the simulation results showed that the meter was able to track the accurate power and energy consumed even in the face of the short-circuiting 3-phases to 1-phase tamper. Also, a typical simulation scenario in the unbalanced line tamper showed a situation where the peak current value in the Blue phase is about 20 A as against about 6 A in the Red and Yellow phases. This results in lower values of power and energy recorded by the meter when compared to what is actually consumed. The deployment of the developed anti-tamper system corrected the abnormality. In all, the ideas presented in the study are essential in combating such two energy theft approaches discussed in this paper.**

Keywords*— Energy Theft, Three Phase Power, Short-Circuiting 3-Phases To 1-Phase Tamper, Exploiting Unbalanced Line Tamper, Detection of Energy Theft, Counter Measures for Energy Theft

I. INTRODUCTION

Over the years, energy theft has been a perennial problem in the power distribution industry [1,2,3,4,5,6,7,8,9]. The incidence of energy theft is particularly high in the developing countries where manual reading of electro-mechanical energy meter located at customer's premises is used [10,11,12,13,14]. By tampering with the energy meter in some ways, the customer can completely or partially bypass the energy meter or influence the meter reading in some ways that amount to losses to the energy distribution organisation [15,16,17,18,19]. In either case, the energy recorded by the meter is not the accurate record of the energy consumed by the customer.

There are several ways that energy theft incidence can be perpetrated [20,21,22,23]. The energy theft approach adopted in some cases depends on the kind of energy meter installed. For instance, the energy theft associated with single phase energy meters may be quite different from the energy theft associated with 3-phase meters. In addition, the capabilities or features of the energy meter can also determine the kinds of energy theft that can be effectively perpetrated in connection with the meter. While simple electro-mechanical energy meters may be able to facilitate the detection of energy theft and the associated implementation of counter measure, sophisticated smart energy meters may be equipped with requisite sensors, actuators and remote communication and alert mechanisms that can altogether facilitate real-time detection and mitigation of energy theft [24,25,26,27,28,29]. Such smart meters may have mechanisms for effective counter measure to some of the energy theft approaches. Notably, such smart meters are built based on some proven approaches for detection and mitigation of different energy theft approaches. Accordingly, in this paper, the detection and counter measures for short-circuiting 3-phases to 1-phase tamper and exploiting unbalanced line tamper are studied. The detection and counter measure approaches are explained with the use of circuit diagrams and analytical models. Furthermore, MATLAB/Simulink modelling and simulations are also used to demonstrate the effectiveness of the detection and counter measure approaches presented in this paper.

II. METHODOLOGY

A. *The Normal Three Phase Connection*

The three phase normal connection is shown in Figure 1 where i_R is the red phase current ; i_Y is the yellow phase current; i_B is the blue phase current ; i_N is the neutral phase current ; V_{RN} is the red phase to neutral voltage ; V_{YN} is the yellow phase to neutral voltage and V_{BN} is the blue phase to neutral voltage. The power equation for normal three phase connection is obtained as follows;

$$P_1 = i_R(V_{RN} - V_{YN}) \quad (1)$$

$$P_2 = i_B(V_{BN} - V_{YN}) \quad (2)$$

Total Power (P_T) is given as;

$$P_T = P_1 + P_2 = i_R V_{RN} - i_R V_{YN} + i_B V_{BN} - i_B V_{YN} \quad (3)$$

$$P_T = i_R V_{RN} + i_B V_{BN} - i_R V_{YN} - i_B V_{YN} \quad (4)$$

$$P_T = i_R V_{RN} + i_B V_{BN} - V_{YN}(i_R + i_B) \quad (5)$$

For a balanced system, the summation of the three line currents is zero, hence;

$$i_R + i_Y + i_B = 0 \quad (6)$$

$$\therefore i_R + i_Y = -i_B \quad (7)$$

Substituting equation (7) into (5) gives ;

$$P_T = i_R V_{RN} + i_B V_{BN} + i_Y V_{YN} \quad (8)$$

The magnitude of the power for a balanced system is given as;

$$i_R = i_Y = i_B = i_L \quad (9)$$

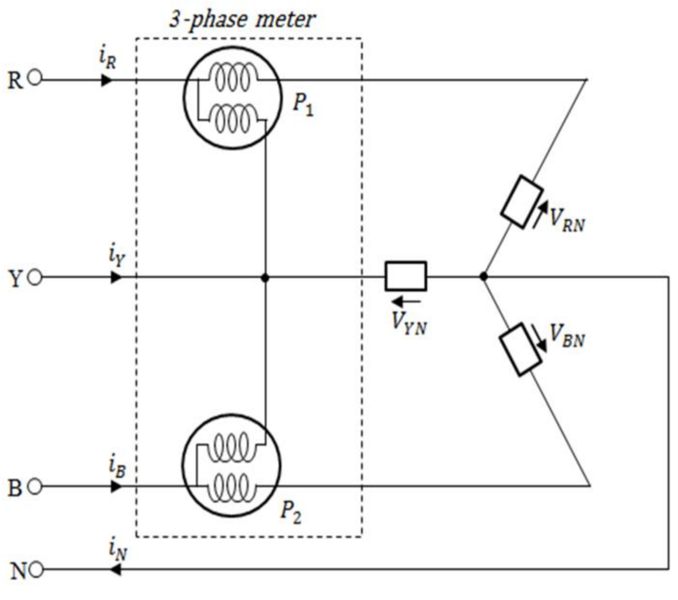
$$V_{RN} = V_{BN} = V_{YN} = V_P = \frac{V_L}{\sqrt{3}} \quad (10)$$

Substituting equations (6) and (7) into (8) gives;

$$P_T = 3\frac{i_L V_L}{\sqrt{3}} = \sqrt{3} i_L V_L \quad (11)$$

B. Short-Circuiting 3-Phases to 1-Phase Tamper

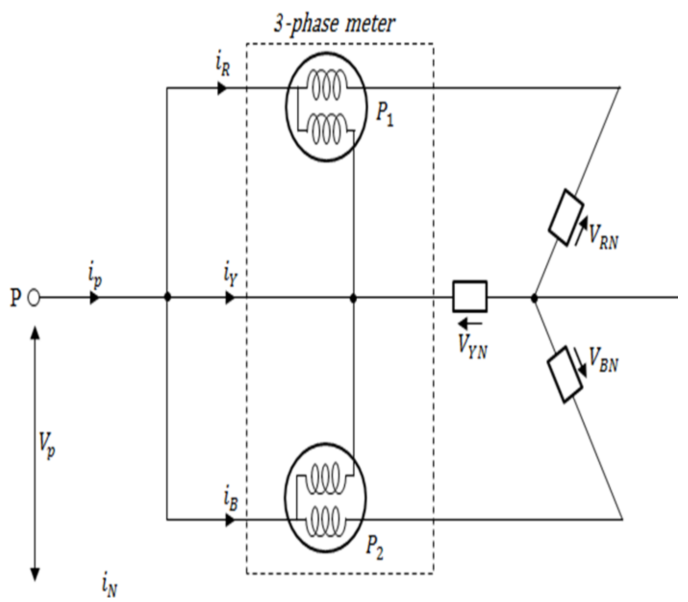
Short-circuiting 3-phases to 1-phase tamper occurs when the three lines input of a 3-phase meter are short-circuited and connected to a 1-phase supply, as shown in Figure 2



Legend for Figure 1

i_R is the Red Phase Current
i_Y is the Yellow Phase Current
i_B is the Blue Phase Current
i_N is the Neutral Phase Current
V_{RN} is the Red Phase to Neutral Voltage
V_{YN} is the Yellow Phase to Neutral Voltage
V_{BN} is the Blue Phase to Neutral Voltage

Figure 1. Three phase normal connection



Where
i_R is the Red Phase Current
i_Y is the Yellow Phase Current
i_B is the Blue Phase Current
i_N is the Neutral Phase Current
V_{RN} is the Red Phase to Neutral Voltage
V_{YN} is the Yellow Phase to Neutral Voltage
V_{BN} is the Blue Phase to Neutral Voltage

Figure 2: Block Diagram of Short-Circuiting 3-Phases to 1-Phase Tamper

C. Analytical Model for the Power Recorded By the 3-Phase Meter under Short-Circuiting 3-Phases to 1-Phase Tamper

The power recorded by the 3-phase meter under short-circuiting 3-phases to 1-phase tamper is obtained as follows;

$$P_1 = i_R(V_{RN} - V_{YN}) \quad (12)$$

$$P_2 = i_B(V_{BN} - V_{YN}) \quad (13)$$

Total Power (P_T) is given as;

$$P_T = P_1 + P_2 = i_R V_{RN} - i_R V_{YN} + i_B V_{BN} - i_B V_{YN} \quad (14)$$

$$P_T = i_R V_{RN} + i_B V_{BN} - i_R V_{YN} - i_B V_{YN} \quad (15)$$

$$P_T = i_R V_{RN} + i_B V_{BN} - V_{YN}(i_R + i_B) \quad (16)$$

Since the three line currents are in phase, there will be current in the neutral line and it is given as;

$$i_R + i_Y + i_B = i_N \quad (17)$$

$$i_R + i_Y = i_N - i_B \quad (18)$$

Substituting equation (18) into (16) gives;

$$P_T = i_R V_{RN} + i_B V_{BN} + i_Y V_{YN} - i_N V_{YN} \quad (19)$$

In short-circuiting 3-phases to 1-phase tamper, the 1-phase current i_P is split into three for the 3-phase, hence;

$$i_R = i_Y = i_B = \frac{i_P}{3} \quad (20)$$

The neutral current is the sum of the three line currents, thus;

$$i_N = i_R + i_Y + i_B = i_P \quad (21)$$

Each of the phase voltages of the 3-phase lines is equal to the phase voltage of the 1-phase line and it is given as;

$$V_{RN} = V_{BN} = V_{YN} = V_P \quad (22)$$

Substituting equations (21) and (22) into (20) gives;

$$P_T = i_R V_P + i_B V_P + i_Y V_P - i_N V_P \quad (23)$$

$$P_T = (i_R + i_Y + i_B)V_P - i_N V_P \quad (24)$$

$$P_T = i_P V_P - i_N V_P = (i_P - i_N)V_P = 0 \times V_P = 0 \quad (25)$$

Therefore, the recorded power by the 3-phase meter under short-circuiting 3-phases to 1-phase tamper is zero.

D. Counter Measure for Short-Circuiting 3-Phases to 1-Phase Tamper

From equations (19), (24) and (25), it is observed that under this tamper, the following expression holds;

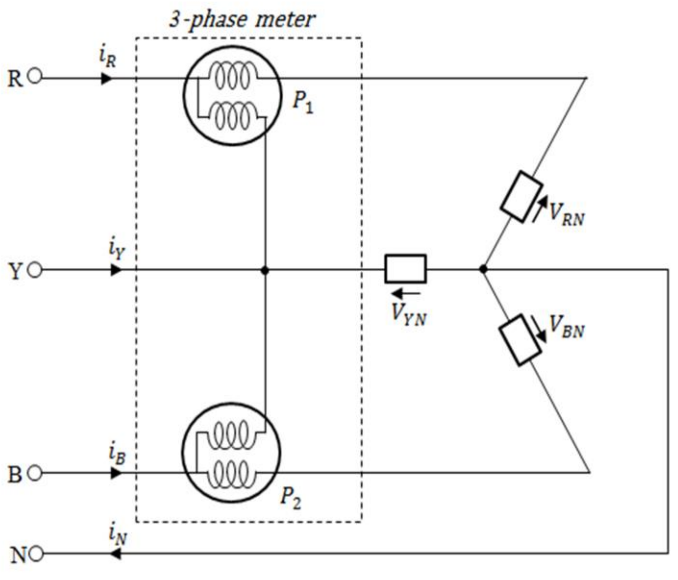
$$i_N V_N = i_N V_P = (i_R + i_Y + i_B)V_P \quad (26)$$

Since the actual consumed power is equal to $(i_R + i_Y + i_B)V_P$, to overcome this tamper, the neutral line current is multiplied by any of the phase voltages, $i_N V_P$, and then added to the power measured. Hence;

$$P_{Total} = P_{measured} + i_N V_{YN} \quad (27)$$

E. Exploiting Unbalanced Line Tamper

Exploiting unbalanced line tamper (Figure 3) is a situation where unbalanced loading of the line occurs which leads to current flowing in the neutral line.



Where
i_R is the Red Phase Current
i_Y is the Yellow Phase Current
i_B is the Blue Phase Current
i_N is the Neutral Phase Current
V_{RN} is the Red Phase to Neutral Voltage
V_{YN} is the Yellow Phase to Neutral Voltage
V_{BN} is the Blue Phase to Neutral Voltage

Figure 3: Block diagram of Exploiting Unbalanced Line Tamper

F. Analytical Model for the Power Recorded By the 3-Phase Meter under Exploiting Unbalanced Line Tamper

The power recorded by the 3-phase meter under exploiting unbalanced line tamper is obtained as follows;

(i) Power Equation

$$P_1 = i_R(V_{RN} - V_{YN}) \quad (28)$$

$$P_2 = i_B(V_{BN} - V_{YN}) \quad (29)$$

Total power is given as;

$$P_T = P_1 + P_2 = i_R V_{RN} - i_R V_{YN} + i_B V_{BN} - i_B V_{YN} \quad (30)$$

$$P_T = i_R V_{RN} + i_B V_{BN} - i_R V_{YN} - i_B V_{YN} \quad (31)$$

$$P_T = i_R V_{RN} + i_B V_{BN} - V_{YN}(i_R + i_B) \quad (32)$$

For a balanced system, the summation of the three line currents is zero, hence;

$$i_R + i_Y + i_B = 0 \quad (33)$$

$$\therefore i_R + i_Y = -i_B \quad (34)$$

Substituting equation (34) into (32) gives;

$$P_T = i_R V_{RN} + i_B V_{BN} + i_Y V_{YN} \quad (35)$$

If the system is not balanced, there will be current in the neutral line and it is given as;

$$i_R + i_Y + i_B = i_N \quad (36)$$

$$i_R + i_Y = i_N - i_B \quad (37)$$

Substituting equation (37) into (32)

$$P_T = i_R V_{RN} + i_B V_{BN} + i_Y V_{YN} - i_N V_{YN} \quad (38)$$

Comparing equations (35) and (38), it is observed that when there is unbalanced loading, the total power captured by the meter is actually less than the actual consumed power by $i_N V_{YN}$.

G. *Counter Measure for Exploiting Unbalanced Line Tamper*

In order to overcome the exploiting unbalanced line tamper, the neutral line current is multiplied by any of the phase voltages (that is, $i_N V_{YN}$) and then added to the total power measured. With this, if there is no unbalancing, $i_N V_{YN} = 0$, since i_N will be equal to zero. If there is unbalancing, $i_N V_{YN} \neq 0$. Thus,

$$P_{Total} = P_{measured} + i_N V_{YN} \quad (39)$$

III. MATHLAB MODELLING, SIMULATION AND RESULTS

The various 3-phase meter tamper and the corresponding counter measures discussed in this paper are modelled and simulated using MATLAB/Simulink version 2019a. The model developed with Simulink is presented in Figure 4. Figures 5 , 6 and 7 show the three phase current, power and energy waveforms for normal operation, shorting of 3-ϕ to 1-ϕ tamper and unbalanced line tamper respectively. As can be observed in Figure 6, the three current signals are in phase, meaning that all the three line inputs to the meter is of the same phase. This situation results in zero power and energy by the meter. With the introduction of the counter measure developed, the meter was able to track the accurate power and energy consumed.

As can be seen in Figure 7, there is a serious imbalanced in the three phases as is noted in the current waveforms. The peak current value in the Blue phase is about 20 A as against about 6 A in the Red and Yellow phases. This results in lower values of power and energy recorded by the meter when compared to what is actually consumed. The deployment of the developed anti-tamper system corrected the abnormality.

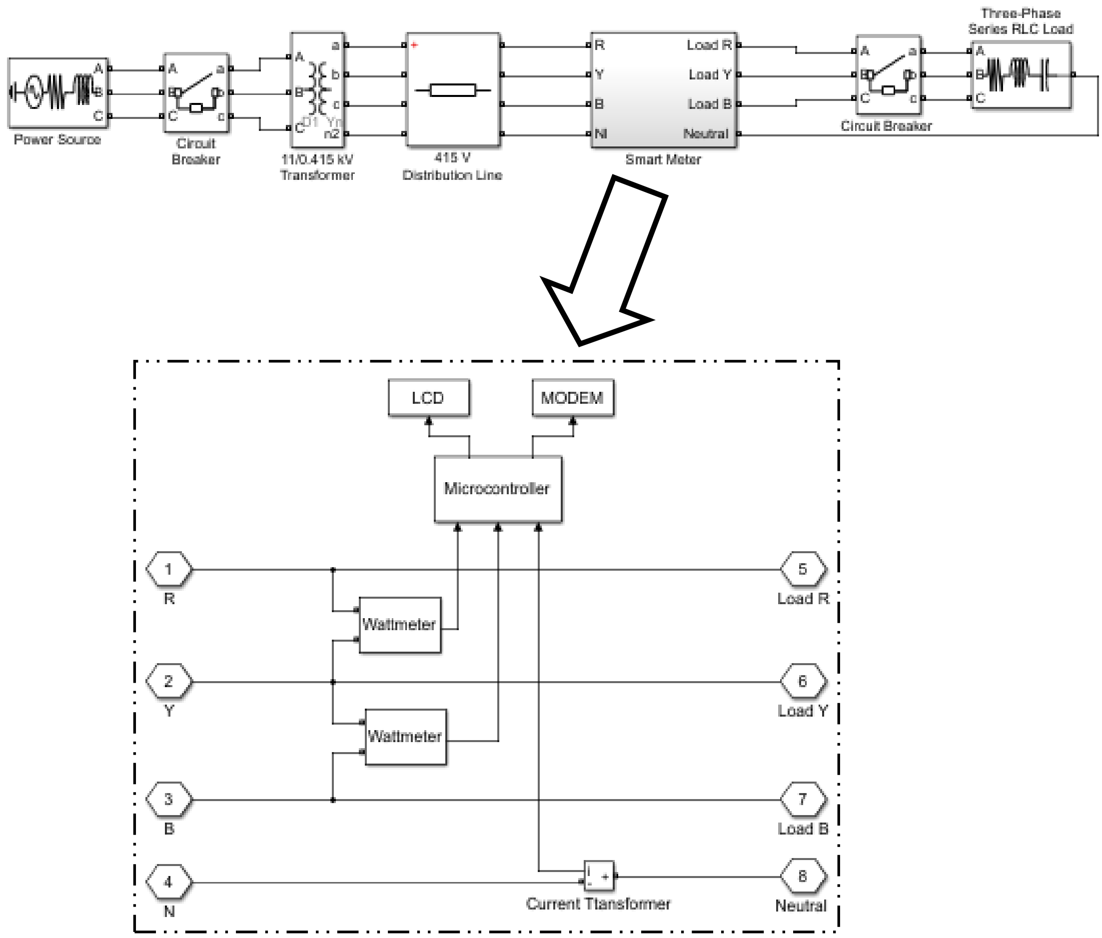
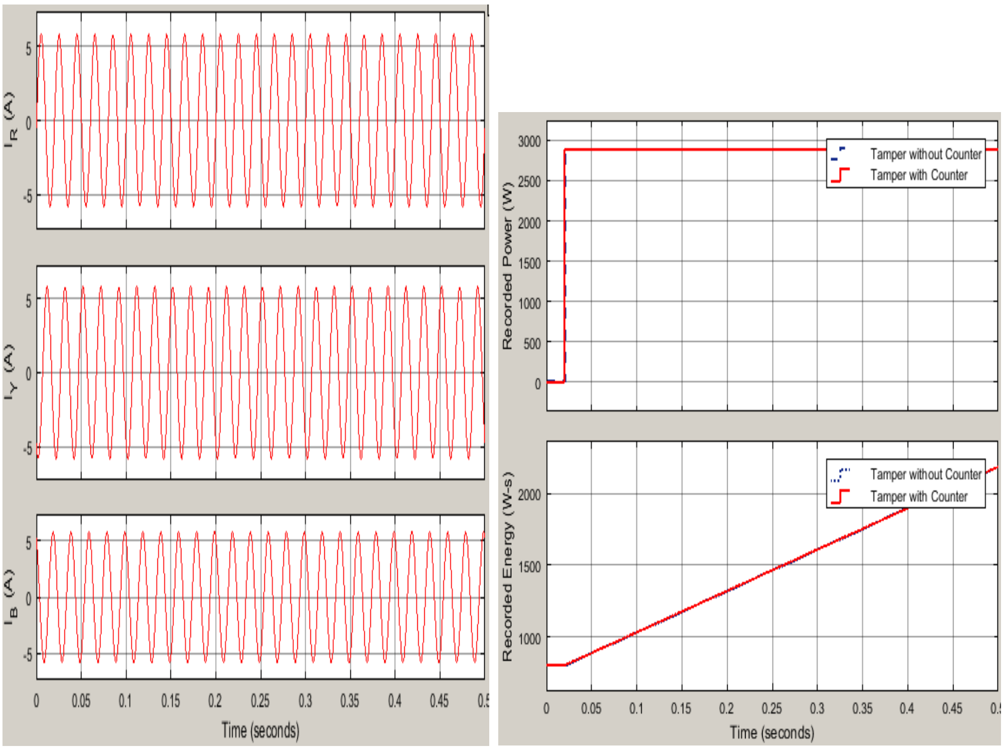
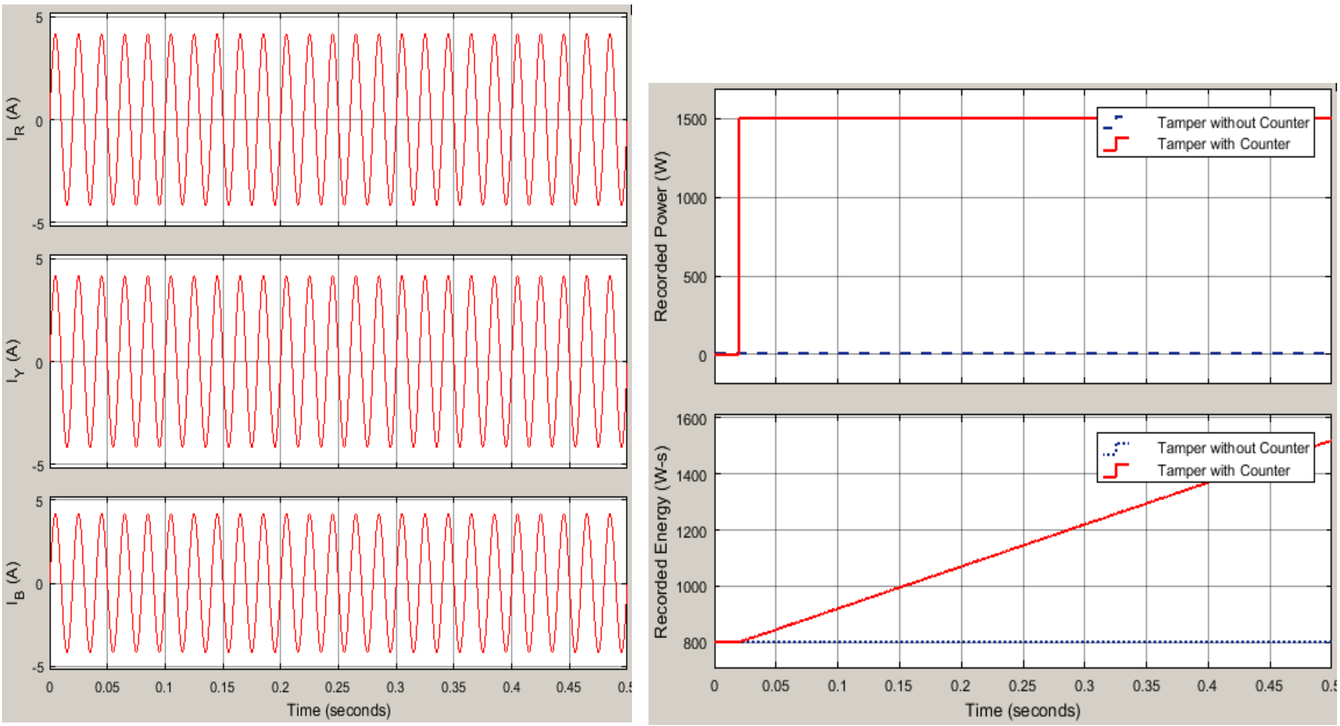


Figure 4: Simulink model of three phase anti-theft system



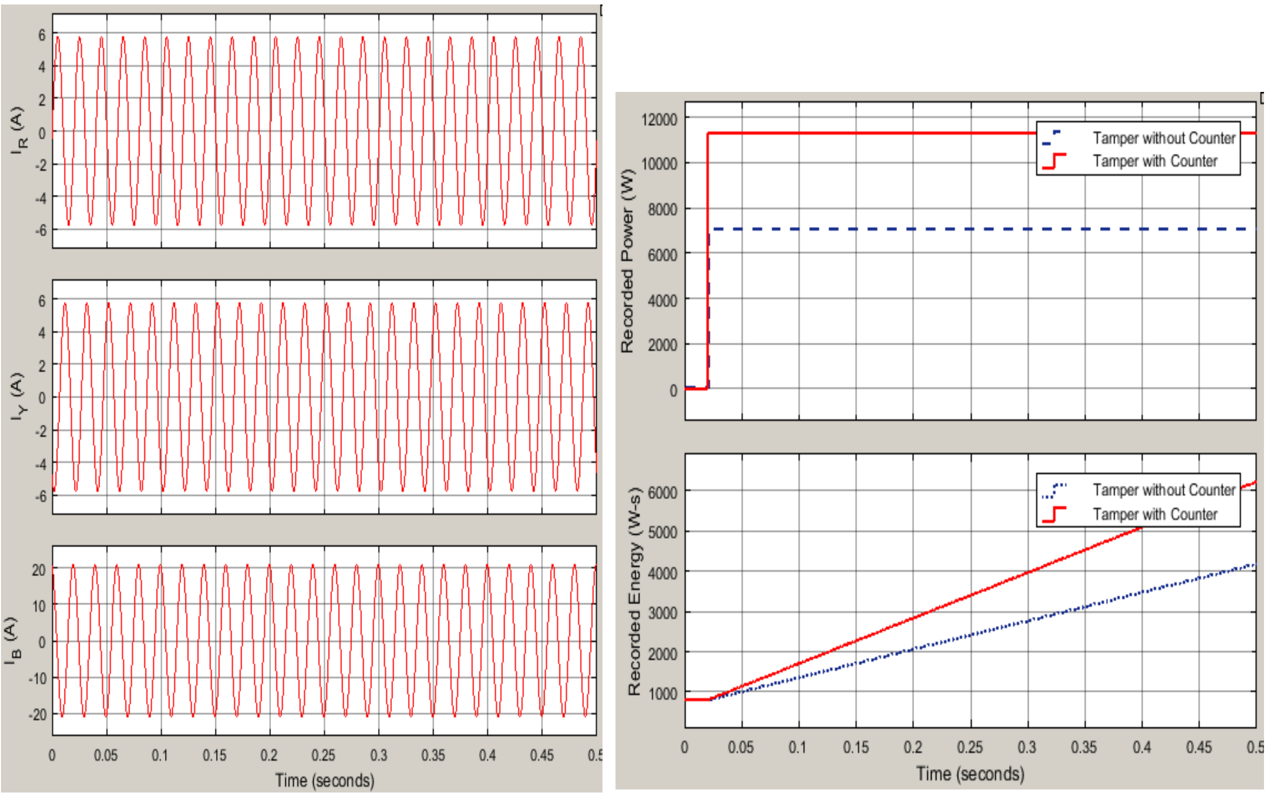
(a) Phase current waveforms *(b) Power*

Figure 5: Normal connection for 3- phase Smart Metering



(a) Phase current waveforms *(b) Power and energy*

Figure 6: 3-Phase Smart Metering: Shorting 3-Phases to 1-Phase tamper



(a) Phase current waveforms *(b) Power and energy*

Figure 7: 3-Phase Smart Metering: Unbalanced Line Tamper

IV. CONCLUSION

Detection of energy theft in respect of short-circuiting 3-phases to 1-phase tamper and exploiting unbalanced line tamper is studied along with the counter measures to mitigate such energy theft. The circuit diagram model and the mathematical expressions associated with the detection and counter measure for the short-circuiting 3-phases to 1-phase tamper and exploiting unbalanced line tamper are presented. Furthermore, the detection approaches for the two energy theft and the counter measures are modelled and simulated in MATLAB software. In all, the results shows that the energy theft approaches studied can be effectively detected and countered by the approaches presented in this paper.

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