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Design and Hybrid Simulation of a Larceny Deterrent Energy Evaluation System

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ABSTRACT

The unreliability of the energy system to provide a proper account of energy utilized by consumers has been a huge burden on the distribution system network. Different metering methods and designs to detect and prevent fraud, employed in the past have proven fruitless, thus signalling the need for a much smarter energy metering system. The most frequent problem is electricity larceny, this has incurred a major economic loss in the energy distribution system. To this end, this paper presents the distinctive design and hybrid simulation of a larceny deterrent energy evaluation system, capable of detecting different methods of energy theft within power consumer premises. The method employed comprises of deep understudy of previous work in this field, a model is proposed and is simulated under good working conditions and several theft situations using MATLAB while the hardware is simulated using Proteus 8.1 and Arduino software. In conclusion, the efficiency of the proposed system is evaluated by employing different electric theft algorithms, with the results indicating significant energy cost savings in the distribution network.

Nomenclature

AC	Alternating current	L	Inductance in Henry
DisCos	Distribution companies	P_{ism}	Power dynamics of intelligent statistical meter
GSM	Global system for mobile communication	P_t	Power rate in kilowatt
ISM	Intelligent statistical meter	P_{um}	Power of user meter
MOA	Miscellaneous offences Act	q	Charge in Coulombs
NERC	Nigerian electricity regulatory commission	V	Total voltage from both meters in volts
NTLs	Non-technical losses	V_{ism}	Voltage of the intelligent statistical meter in volts
SVM	Support vector machine	V_{um}	Voltage of the user meter in volts
Symbols		$⋋_1$	Damping force parameter
C	Capacitance in Farad	$⋋_1 \, p_{ism}$	Theft rate for intelligent statistical meter
E_{ism}	Power dynamics of intelligent statistical meter	$⋋_{1ps}$	Theft rate from a single power source
E_t	Energy dynamics of Unal meter	$⋋_2 \, p_{um}$	Theft rate for the power user meter
E_{usm}	Energy dynamics of User meter	λ_t	Power theft rate
G_t	Golden's theft rate model		

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1. Introduction

Power larceny is more dominant in developing countries [1] than it is in industrialized nations [2]. The peak energy larceny incidences in evolving nations are influenced largely by poverty [3], although insatiability and ethical negligence may result in other cases [4]. Further, some citizen sees the electricity from the national grid as a gift, this mentality of users tend to contribute to the energy larceny rate [5]. Other origins of energy larceny are the insufficient supply of energy meters by DisCos to all approved users who are willing to pay for their power consumption. However, these particular users often time get appraised energy bills, which significantly contribute to NTLs for the distribution companies [6]. Furthermore, for some sections of the year energy users with approved connections and meters also get irregular appraised energy bills. Consequently, appraised energy bills increase speedily for these users, and if not attended to accumulate making it seem the users are nonpayers [7]. Furthermore, this liability is constant on the energy bills of the consumers and is claimed by the energy supply company to be paid. This unpleasant experience encourages the reluctance of candid users to pay up their energy bills. Finally, the elevated state of unemployment in Nigeria [8, 9] translates to severe commercial situations for energy users, evidently supplementing energy larceny in Nigeria. To this end, the energy cracks, probable reasons for larceny in the distribution system network, have ignited the determined review and design of an intelligent energy deterrent model to curb the issue of power theft.

Energy larceners utilize several techniques. However, two typical ways employed by energy users are detour-connection to grid supply line and power meter altering [10]. An illegal way of altering a meter involves the addition of an external device to obstruct the rotational dynamics of the disc within the power meter [11]. This adversely upsets the meter reading rate and consequently decreases the energy usage of the customer. Besides, an energy meter can be detour-connected to the source line, without contact with the meter terminal points [12].

The overall aims of this research are outlined as follows:

(a) Identify the constraints and problems associated with energy theft in Nigeria.
(b) Design a theft-free energy monitoring system.
(c) Simulate the design of the theft-free energy monitoring system.

2. Reviewed Articles Related to this Study

Quite a several researchers have highlighted measures to curtail and prevent electricity shortages. In [13], the authors proposed an integrated energy recognition system by employing a Kalman filter, along with a privacy-preserving power detection-based algorithm to recognize unapproved users.

The simulation of an intelligent anti-theft energy system is proving to gain increasing success. The authors in [14] opined on the distinctive model of an automated anti-theft system, using a high voltage capacitor bank connected to the grid. The proposed system detects an illicit connection and then sends a high pulse voltage to prickle out the illicit load, and simultaneously preserves the uninterrupted supply to permitted loads.

The authors in [15], carried out a comparative review analysis of power theft non-technical losses associated with transmission and distribution networks using the neural SVM model, the challenges proposed by these losses were analysed and the future way forward in dealing with the losses were also presented.

The authors in [16], proposed a conceptual approach to derive both the approximate location and extent of energy theft at an exact location in real-time. The proposed system employs power line carriers and an improved metering mechanism for an intelligent distribution network. Nonetheless, this design functions accurately with exact data of location and degree of energy theft.

The authors in [17], referred to the scarcity of studies addressing the increasing energy theft in the distribution network, they however proposed a wireless detection method of energy theft using a buzzer and GSM module in the model. An electromagnetic relay senses instantaneously any larceny action and initiates a blocking process swiftly with aid of the micro-controller. Further, the design limitations, recommendations and future research directions are presented in this study.

3. Methodology

In the context of this paper the methodology employed is outlined as follows:

(a) Review of related literature by identifying the various factors that have led to energy theft and tampering and also the gap in metering existing consumers on the distribution network.
(b) Design the larceny-free monitoring system and simulate the proposed system using MATLAB
(c) Evaluate the efficiency of the system using power theft dynamics and algorithms.

3.1. Design of the Proposed System

The proposed design for the energy theft evaluation system coupled with the connections of various units and the flow of signal between various units is depicted in Fig. 1.

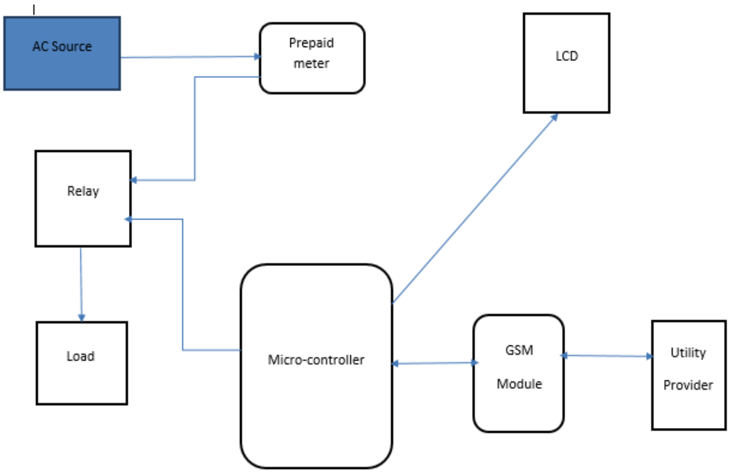

Fig. 1 The proposed energy larceny deterrent model.

3.2. Energy Theft Dynamics and Algorithms

The energy theft dynamics are evaluated using a novel non-linear deterministic ordinary differential equation. The sensitivity analysis which is the case of altered electronic element trace in a damped meter (altered user meter) is also discussed. Numerical simulation using MATLAB algorithm is shown as follows:

$$\lambda_t = \frac{V_{um}}{V_{um}+V_{ism}} \tag{1}$$

$$V - \lambda_t \tag{2}$$

Where λ_t is the power theft rate, V_{um} is the voltage of the user meter in volts, V_{ism} is the voltage of the intelligent statistical meter in volts and V is the total voltage from both meters in volts.

The implication of equation (2) is that the voltage is lagged by the energy theft at a rate λ_t. The larceny-free equilibrium is expressed as equation (3).

$$E_{ism} = E_{ism}^{**} \tag{3}$$

Thus, at any point V_{ism} varies, if:

$E_{usm}^{**} > E_{ism}^{**}$, then power theft occurred,

$E_{ism}^{**} > E_{usm}^{**}$, no energy theft,

$E_{ism}^{**} = E_{usm}^{**}$, no energy theft.

Model Formulation: The dynamics of energy are viewed as a compartmental system, consisting of

(a) Energy dynamics of intelligent statistical meter, E_{ism}.
(b) Energy dynamics of User meter, E_{usm}.
(c) Energy dynamics of Unal meter, E_t.

3.3. Energy Dynamics of an Intelligent Statistical Meter (E_{ism})

The power dynamics of the intelligent statistical meter are a function of the source voltage as registered by the ISM. It is observed that when the system is initiated with a voltage of periodic function ($V_{ism}sin$(t)), the damping spurred by the inductor and capacitor tends to attenuate the oscillation at a rate L and C respectively. Consider the LRC circuits (Fig. 2). An effective RLC circuit for energy dynamics by applying Kirchhoff's law.

From Kirchoff's second law, the sum of the voltages equals the impressed voltage on the circuit i.e.,

$$L\frac{di}{dt} = E(t) - Ri - \frac{1}{c}q \tag{4}$$

Applying chain rule

$$\frac{dp}{dt} = \frac{dI}{dt} * \frac{dp}{dI} \tag{5}$$

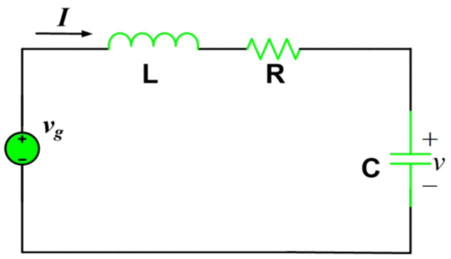

Fig. 2 An effective RLC circuit for energy dynamics by applying Kirchhoff's law.

Set:

$$i = \frac{dQ}{dt} \tag{6}$$

$$\frac{dp}{dt} = v \tag{7}$$

Substitute equations (4), (5) and (6) into equation (3), which gives

$$\frac{dp_{ism}}{dt} = \frac{V_{ism}}{L}\left(\sin(t) - \frac{q}{c}\right) - \lambda_{1ps} \tag{8}$$

Where P_{ism} is the power dynamics of intelligent statistical meter, L is the inductance in Henry, q is the charge in Coulombs, C is the capacitance in Farad and λ_{1ps} is the theft rate from a single power source.

3.4. Energy Deterrent Dynamics of User Meter

The source voltage which is a periodic function ($V_{ism} sin$(t)), is lagged by the power theft rate λ. The power registered by the usage meter is further diminished by damping at a rate λ_2.

$$\frac{dp_{um}}{dt} = \frac{(V_{ism} - \lambda_t)}{L}\left(\sin(t) - \frac{q}{c}\right) - \lambda_2\, p_{um}. \tag{9}$$

Where P_{um} is the power of user meter and $\lambda_2\, p_{um}$ is the theft rate for power user meter.

3.5. Energy Deterrent Dynamics of Unalmeter

Theft dynamics are viewed as a coupled system of equations (8) and (9).

$$\frac{dp_t}{dt} = \lambda_t * \left(\sin(t) - \frac{q}{c}\right) + \lambda_2\, p_{um} + \lambda_1\, p_{ism}. \tag{10}$$

Where P_{t} is the power rate in kilowatt, and $\lambda_1\, p_{ism}$ is the theft rate for intelligent statistical meter.

Combining equations (8), (9) and (10), gives

$$\begin{aligned} \frac{dp_{ism}}{dt} &= \frac{V_{ism}}{L}\left(\sin(t) - \frac{q}{c}\right) - \lambda_1\, p_s \\ \frac{dp_{um}}{dt} &= \frac{(V_{ism} - \lambda_t)}{L}\left(\sin(t) - \frac{q}{c}\right) - \lambda_1\, p_{um} \\ \frac{dp_t}{dt} &= \lambda_t * \left(\sin(t) - \frac{q}{c}\right) + \lambda_2\, p_{um} + \lambda_1\, p_{ism}. \end{aligned} \tag{11}$$

Equation (11) is the model of power theft dynamics incorporated with anti-power theft parameters (damping system). The parameters and adjustable variables for the energy theft model are interpreted and deduced as shown in Table 1.

3.6. Power Theft Analysis in the Absence of Meter By-Passing

The model of equation (11) reduces to

$$\begin{aligned} \frac{dp_{ism}}{dt} &= \frac{V_{ism}}{L}\left(\sin(t) - \frac{q}{c}\right) \\ \frac{dp_{usm}}{dt} &= \frac{(V_{ism} - \lambda_t)}{L}\left(\sin(t) - \frac{q}{c}\right) \\ \frac{dp_t}{dt} &= \lambda_t \left(\sin(t) - \frac{q}{c}\right) \end{aligned} \tag{12}$$

Table 1. Depiction of parameters and variables for energy theft model.

Parameter	Interpretation
V_{ism}	Voltage registered by ISM
R	Resistor
L	Inductor
C	Capacitor
Q	Quantity of charge
λ_1	damping force parameter
λ_2	damping force parameter
Variables	**Interpretation**
E_{ism}	Energy of ISM
E	Energy of user meter
E_t	Energy of unmeter (power theft)

Let η_t be the range-bound for the power theft (mathematically η_t= eigenvalue value. The Jacobian of equation (12) is obtained as follows:

$$J = \begin{bmatrix} \eta_t - V_{ism}\left(\sin(t) - \frac{q}{c}\right) & 0 \\ 0 & \eta_t - (V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c}) \end{bmatrix} \quad (13)$$

Appling $det(J)$ = 0, gives:

$$\left(\eta_t - V_{ism}\left(\sin(t) - \frac{q}{c}\right)(\eta_t - \lambda_t)(\sin(t) - \frac{q}{c}\right)) - 0 = 0$$

Further simplification gives:

$$\eta_t^2 - \eta_t\left(\sin(t) - \frac{q}{c}\right)(2V_{ism} - \lambda_t) + V_{ism}(V_{ism} - \lambda_t)\left(\sin(t) - \frac{q}{c}\right) = 0. \quad (14)$$

Thorough algebraic simplification gives

$$\eta_t = \frac{(2*V_{ism} - \lambda_t)\left(\sin(t) - \frac{q}{c}\right) + \sqrt{(2*V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c}) - 4V_{ism}(V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c})}}{2} \quad (15)$$

$$\eta_t = \frac{(2*V_{ism} - \lambda_t)\left(\sin(t) - \frac{q}{c}\right) - \sqrt{(2*V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c}) - 4V_{ism}(V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c})}}{2} \quad (16)$$

For an altered user meter, the range-bound of the usage meter is defined by equations (15) and (16); thus, the efficiency of the altered user meter is shown in Tables 2 and 3. Also, equations (17) and (18) depict the percentage of range bounds in equations (15) and (16) for an altered user meter respectively. While for accurate range bounds in relation to (17) and (18), unaltered user meter λ_t is set to zero.

$$\%\eta_t = \frac{(2*V_{ism} - \lambda_t)\left(\sin(t) - \frac{q}{c}\right) + \sqrt{(2*V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c}) - 4V_{ism}(V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c})}}{2} * \frac{100}{1}] \quad (17)$$

$$\%\eta_t = \frac{(2*V_{ism} - \lambda_t)\left(\sin(t) - \frac{q}{c}\right) + \sqrt{(2*V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c}) - 4V_{ism}(V_{ism} - \lambda_t)(\sin(t) - \frac{q}{c})}}{2} * \frac{100}{1}] \quad (18)$$

Table 2. Efficiency bound of unaltered user meter.

Variational values V_{ism}	Values of range-bound of unaltered user meter	Efficiency
150	98.9623-98.9623	98.9623
160	98.9104-98.9104	98.9104
170	98.8586-98.8586	98.8586
180	98.8067 - 98.8067	98.8067
190	98.7548-98.7548	98.7548
200	98.7029-98.7029	98.7029
210	98.6510-98.6510	98.6510
220	98.5991-98.5991	98.5991

Table 3. Efficiency bound of altered user meter

Variational values, V_{ism}	**Values of range-bound of unaltered user meter**	**Efficiency**	$\leftthreetimes_t$
150	98.9623-98.9623	98.98	0.02
160	98.9104-98.9104	98.92	0.02
170	98.8586-98.8586	98.86	0.02
180	98.8067 - 98.8067	98.1	0.02
190	98.7548-98.7548	98.76	0.02
200	98.7029-98.7029	98.71	0.02
210	98.6510-98.6510	98.66	0.02
220	98.5991-98.5991	98.61	0.02

Table 4. Variational values of the power theft analysis, their range-bound of unaltered user meter and associated damping characteristic values.

Variational values V_{ism}	**Values of range-bound of unaltered user meter**	$\leftthreetimes_t$	$\leftthreetimes_1$	$\leftthreetimes_2$
150	98.9925-98.9623	0.02	0	0.00005
160	98.9416-98.9104	0.02	0	0.00005
170	98.8907-98.8586	0.02	0	0.00005
180	98.8398-98.8067	0.02	0	0.00005
190	98.7890-98.7548	0.02	0	0.00005
200	98.7381-98.7029	0.02	0	0.00005
210	98.6872-98.6510	0.02	0	0.00005
220	98.6363-98.5991	0.02	0	0.00005
230	98.5854-98.5472	0.02	0	0.00005

3.7. Power Theft Analysis in the Presence of Damping

Consider the critical case (integration of bypassing of meter and altered meter. In this scenario, the Jacobian matrix is utilized from the model of equation (8) with the associated variational values, range-bound of unaltered user meter and their damping characteristics depicted in Table 4.

$$J = \begin{bmatrix} \eta_t - V_{ism}\left(\sin(t) - \frac{q}{c}\right) - \leftthreetimes_1 & 0 \\ 0 & \eta_t - (V_{ism} - \leftthreetimes_t)(\sin(t) - \frac{q}{c}) - \leftthreetimes_2 \end{bmatrix}$$

Solving $det(J)$ = 0, gives

$$\eta_t^2 - \eta_t\left(\left(\sin(t) - \frac{q}{c}\right) - \leftthreetimes_2\right)(2V_{ism} - \leftthreetimes_t) + V_{ism}(\sin(t) - \frac{q}{c}))$$
$$+V_{ism}(V_{ism} - \leftthreetimes_t)((\sin(t) - \frac{q}{c})\left(\left(\sin(t) - \frac{q}{c}\right) - \leftthreetimes_2\right) = 0. \tag{19}$$

From equation (19), the sensitivity values for voltage, charge, capacitance and damping value estimated and introduced to the sensitivity analysis of user meter in equation (20) are depicted in Table 5.

3.8. Sensitivity Analysis of User meter

In ascertaining how best to reduce power theft due to damping of the user meter, it is expedient to know the comparative importance of the circuit components in the user meter, responsible for damping. Sensitivity analysis enables us to measure the relative change in the state variable P_{ism} and P_t, when a parameter changes. Contextually, it allows us to measure the relative change of the user when a component in the circuit is altered. Further, the normalize sensitivity forward index of a variable *y* that depends on a parameter q is defined as

$$\prod_q^y = \frac{\partial y}{\partial q} * \frac{q}{y} \tag{20}$$

Let $y = \eta_t$ and $q = (V_{ism}, \leftthreetimes_t, \leftthreetimes_1, \leftthreetimes_2\ q, c)$. Applying definition (19) on the set of q, gives:

$$\frac{\partial \eta_t}{\partial V_{ism}} = \frac{1}{2}(2((\sin(t) - \frac{q}{c}) - \leftthreetimes_t)\frac{(\sin(t) - \frac{q}{c}) - \leftthreetimes_t) - 4v(\sin(t) - \frac{q}{c}) - 4(v - \leftthreetimes_t)(\sin(t) - \frac{q}{c})}{2\sqrt{-4v(v - \leftthreetimes_t)(\sin(t) - \frac{q}{c}) + (2V - \leftthreetimes_t)(\sin(t) - \frac{q}{c})}} \tag{21}$$

Further simplification gives

$$\frac{\partial \eta_t}{\partial V_{ism}} = \frac{\left(-q+csin(t)[1+2\leftthreetimes_t-4v+2\sqrt{\frac{(\leftthreetimes_t-2v-4\leftthreetimes_t v-4v^2)(q-csin(t))}{c}}\right)}{2c\sqrt{\frac{\leftthreetimes_t-4\leftthreetimes_t v-2v(2v-1)(q-csin(t))}{c}}} \tag{22}$$

$$\frac{\partial \eta_t}{\partial q} = \frac{1}{2}\left(-\frac{2v-\leftthreetimes_t}{c} + \frac{\frac{4v(v-\leftthreetimes_t)}{c}-\frac{2v-\leftthreetimes_t}{c}}{2\sqrt{-4v(v-\leftthreetimes_t)(\frac{q}{c}+\sin(t))+(2v-\leftthreetimes_t)(\frac{q}{c}+\sin(t))}}\right. \tag{23}$$

Further simplification gives:

$$\frac{\partial \eta_t}{\partial q} = \frac{1}{4}\left(-\frac{2(\leftthreetimes_t-2v}{c} + \frac{\sqrt{\frac{(\leftthreetimes_t-4\leftthreetimes_t v+2v)(q-csin(t)}{c}}}{q-csin(t)}\right) \tag{24}$$

$$\frac{\partial \eta_t}{\partial c} = \frac{1}{2}\left(\frac{q(2v+\leftthreetimes_t)}{c^2} + \frac{\frac{-4qv(v-\leftthreetimes_t)}{c^2}+\frac{q(2v-\leftthreetimes_t)}{c^2}}{2\sqrt{-4v(v-\leftthreetimes_t)(\frac{q}{c}+\sin(t))+(2v-\leftthreetimes_t)(\frac{q}{c}+\sin(t))}}\right) \tag{25}$$

$$\frac{\partial \eta_t}{\partial c} = \frac{1}{4}\left[\left(-\frac{2q(2v-\leftthreetimes_t)}{c^2} + \frac{q(2(1-2v)+\leftthreetimes_t(4v-1)}{c^2\sqrt{\frac{(\leftthreetimes_t-4\leftthreetimes_t v+2v(2v-1))(q-csin(t)}{c}}}\right]\right. \tag{26}$$

$$\frac{\partial \eta_t}{\partial c} = \frac{1}{2}\left[-\frac{\leftthreetimes_t+2v}{c} + \frac{\frac{4v(v-\leftthreetimes_t)}{c}-\frac{\leftthreetimes_2+2v}{c}}{2\sqrt{-4v(-\leftthreetimes_t+v)(\frac{q}{c}+\sin(t))+(-\leftthreetimes_t+2v)(-\frac{q}{c}+\sin(t))}}\right. \tag{27}$$

$$\frac{\partial \eta_t}{\partial \leftthreetimes_t} = \frac{1}{4}\left[2\frac{(\leftthreetimes_t-2v)}{c} + \frac{\sqrt{\frac{(\leftthreetimes_t-4\leftthreetimes_t v+2v(-1+2v))(q-csin(t)}{c}}}{q-csin(t)}\right] \tag{28}$$

Table 5. Sensitivity values for voltage, charge, capacitance and damping estimated and introduced to the theft power analysis

Parameters	Sensitivity Value
V_{ism}	-44.45
Q	-0.0001869
C	0.00001869
$\leftthreetimes_t$	0.0400745

The threshold value of power theft is the Eigenvalue (root) of the secular matrix with the largest radius. Solving for the Eigenvalue with the largest radius in equation (21) gives:

$$G_t = \frac{(2*V_{ism}-\leftthreetimes_t)(\sin(t)-\frac{q}{c})+\sqrt{(2*V_{ism}-\leftthreetimes_t)(\sin(t)-\frac{q}{c})-4V_{ism}(V_{ism}-\leftthreetimes_t)(\sin(t)-\frac{q}{c})}}{2} \tag{29}$$

Equation (29) depicts the final model equation that determines if power theft will occur based on implications of the damping parameter introduced. In this scenario, the inferred parameter (λ_2) is the only damping parameter incorporated in equation (19) as $\leftthreetimes_t$ is set to zero for unaltered user meter. The implication is that power theft will occur if the user meter is damped. The contour plot (Fig. 3 in section 4 of this paper) depicts the influence of the damping parameter at varying values. It is important to note that, when:

(a) λ_2= 0, Implies unaltered user meter.
(b) λ_2>0, Implies altered user meter.

4. Simulation Results and Discussion

The obtained simulated results when the meter is (and is not) altered is depicted as follows in Figs. 3 and 4; however, Fig. 3 also represents the contour plot influenced damping parameter at varying values as shown. When user meter is altered (λ_2 >0), the threshold parameter values are all less than zero, thus, satisfying condition one (Fig. 3). For condition 2, the contour plot and simulated result when user meter is not altered is depicted in Fig. 4. When user meter is altered (λ_2 = 0), the threshold parameter values are positive, thus, satisfying condition two.

From the contour plots and dynamics of smart statistical meter (Fig. 5), it is observed that for a range of 50 to infinity the damping condition one where $\lambda_2 > 0$ holds, coupled the estimated output voltage range of about 0.5-20 volts as shown in Table 6. The linearizing effect of the user meter when the user meter is damped is shown in Fig. 6. From the plot dynamics, the user meter sleep below (linearize) the intelligent statistical meter. In this case the user metered is critically damped, thus the user meter becomes undetected by the intelligent statistical meter.

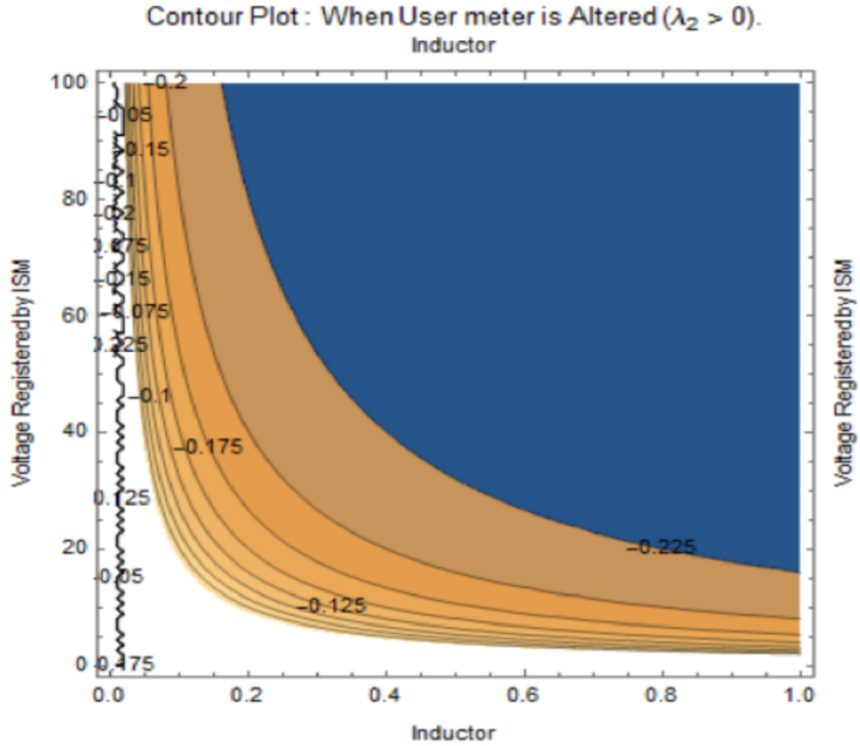

Fig. 3 The contour plot and simulated result when user meter is altered using the theft energy dynamics.

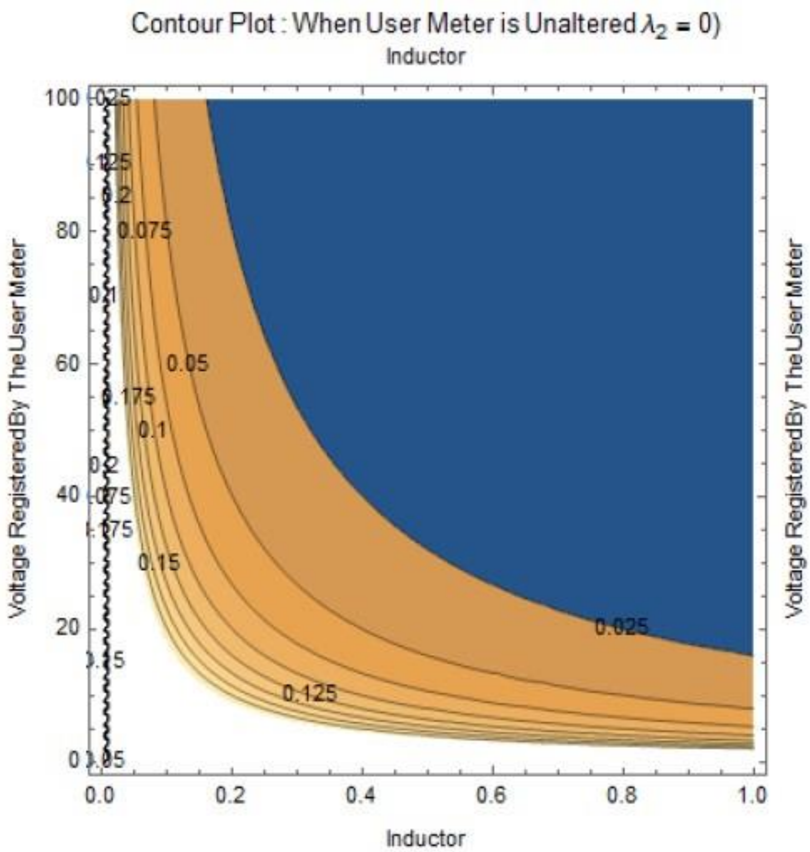

Fig. 4 Contour plot and simulated result when user meter is not altered using energy theft dynamics.

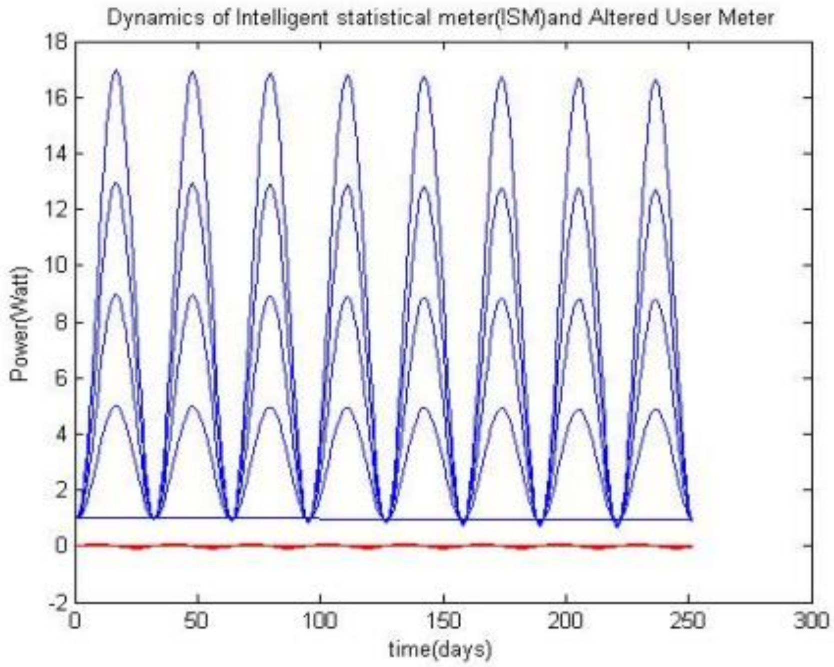

Fig. 5 Dynamics of intelligent statistical meters [18].

From the contour plots and dynamics of the smart statistical meter, we observed that for a damping value of 0 the damping condition two where $\lambda_2 = 0$ holds, coupled with the estimated output voltage range of about 0.5 volts as shown in Table 7. When the damping parameter is trivialized, it is noted that the amplitude of the intelligent statistical meter and the user meter are in their respective steady state (Fig. 7). Thus, power theft fails to occur, as long the power source registered by the intelligent statistical meter exceeds the power consumed by the user meter.

In relation to Table 6, the adjusted damping value for condition one is shown in Table 8 along with the expected output voltage range to check the intelligence of the energy theft model. Small perturbation from the damping parameter, effect resonance on the power registered by the user meter. The unsteady state of the dynamics of the user meter implies that the user meter is damped. Thus, power theft exists. In relation to Table 7, the adjusted damping value for condition one is shown in Table 9 along with the expected output voltage range to check the intelligence of the energy theft model. Also, Fig. 8 represents the dynamics of Ism and altered user meter at various power values in watt in relation to time.

Table 6. Estimated value range for damping condition one and output voltage.

Parameters	Values
λ_2	50-∞
V_0	0.5-20

Table 7. Estimated value range for damping condition two and output voltage.

Parameters	Values
λ_2	0
V_0	0.5

Table 8. The adjusted damping value for condition one along with the expected output voltage range.

Parameters	Values
λ_2	0.1
V_0	0.5-20

Table 9. The adjusted damping value for condition two along with the expected output voltage range.

Parameters	Values
λ_2	0.000001
V_0	0.5:0.2:2

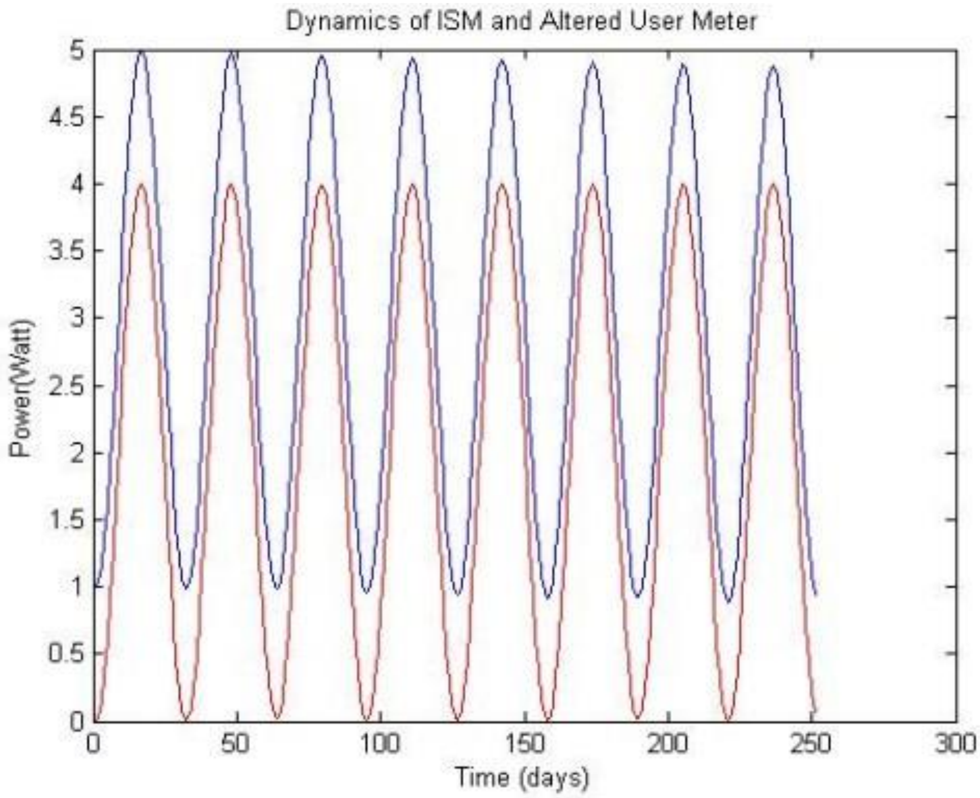

Fig. 6 Dynamics of ISM and altered user meter [19].

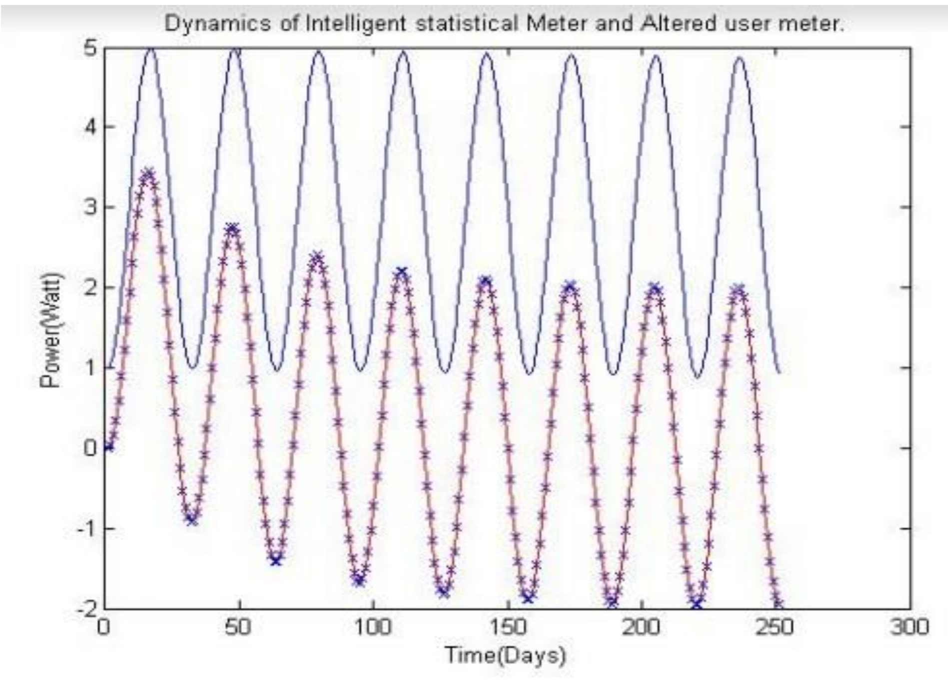

Fig. 7 Dynamics of intelligent statistical meter and altered user meter [20].

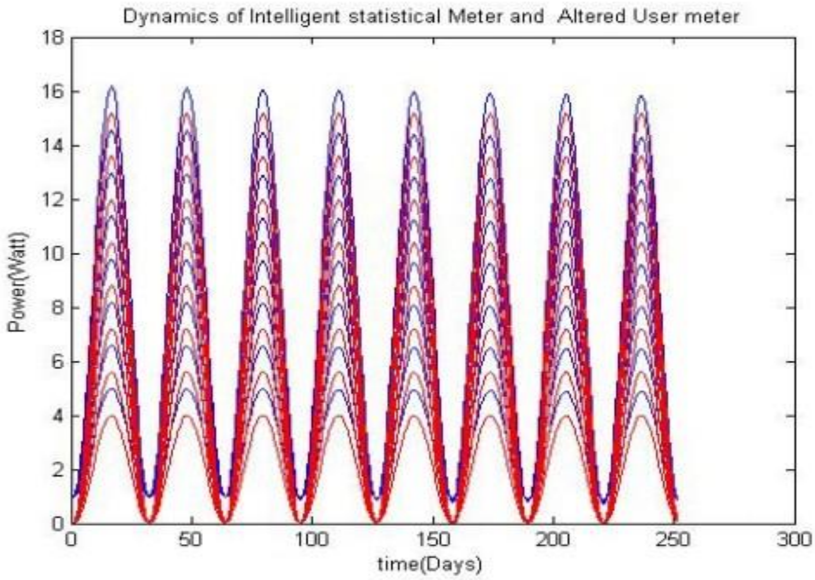

Fig. 8 Dynamics of Ism and altered user meter [21].

The variation effect of the input voltage on the smart statistical meter and the user meter has an effect on the dynamics of both meters and this is evident in the plots comparing ISM with altered user meter in Fig. 9. In relation to Table 9, the final adjusted damping value for condition two is shown in Table 10 along with the expected output voltage range of 0.5:0.2:2. Table 11 depicts the final value of ISM voltage, inductance, charge, capacitance, and final damping values at various points of the simulated contour plots of the energy theft algorithm.

Table 10. The final adjusted damping value for condition two

Parameters	Values
λ_2	0.0001
V_0	0.5:0.2:2

Table 11. Final value of ISM voltage, inductance, charge, capacitance, and final damping values at various points of the simulated contour plots.

Parameters	Values
Vism	0.5
L	0.25
Q	2.05E-05
C	2.31
ε_t	0.0002
λ_1	0.0009
λ_2	0.000101 (varies)
λ_3	0.00004

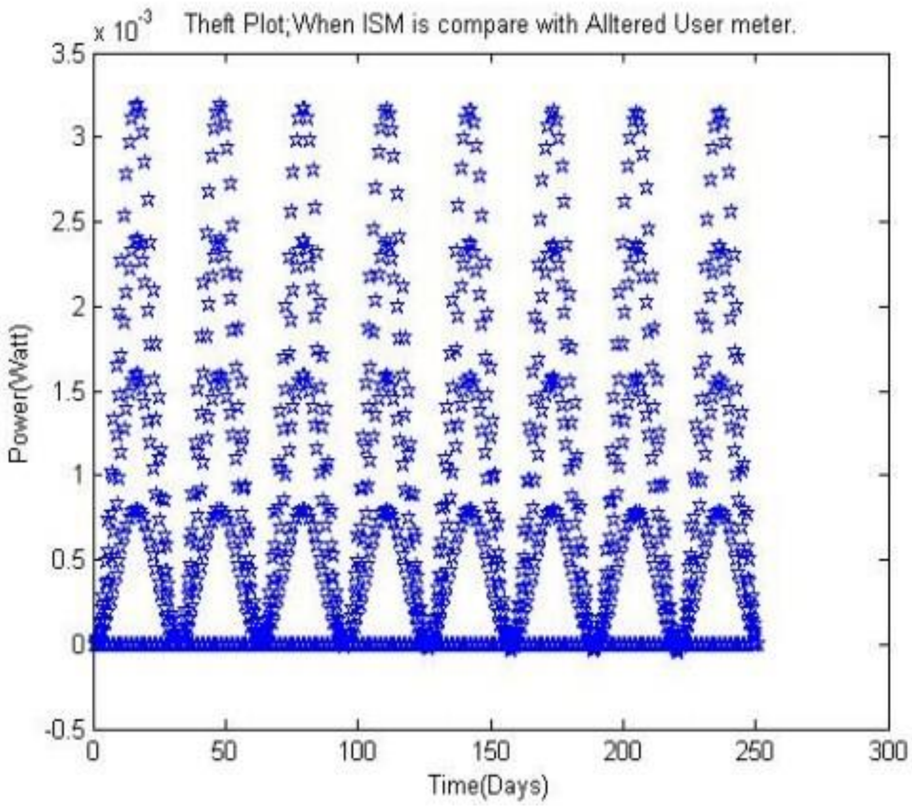

Fig. 9 Various plots comparing ISM with altered user meter [22].

The final hardware simulation using Proteus 8.1 based on Arduino is represented in Fig. 10. The various sections of the model from the AC source, to the protection unit, the microprocessor and calculated regulation using various specified electronic components coupled signal flow to the GSM module are shown in the circuitry diagram of the energy deterrent system.

Fig. 10 depicts the complete feasibility of the energy theft algorithm, with high efficiency of the various specified units, the microprocessor actuates whenever any of the damping conditions are met ad then sends the processed signal to the GSM module. The GSM module then responds to this signal distinguishing if it's an illegal or approved user access or connections and intelligently then prompts the distribution energy provider of such connections in real-time. This reviewed model can appropriately function for not just a single-phase meter but also works efficiently with a 3-phase digital meter.

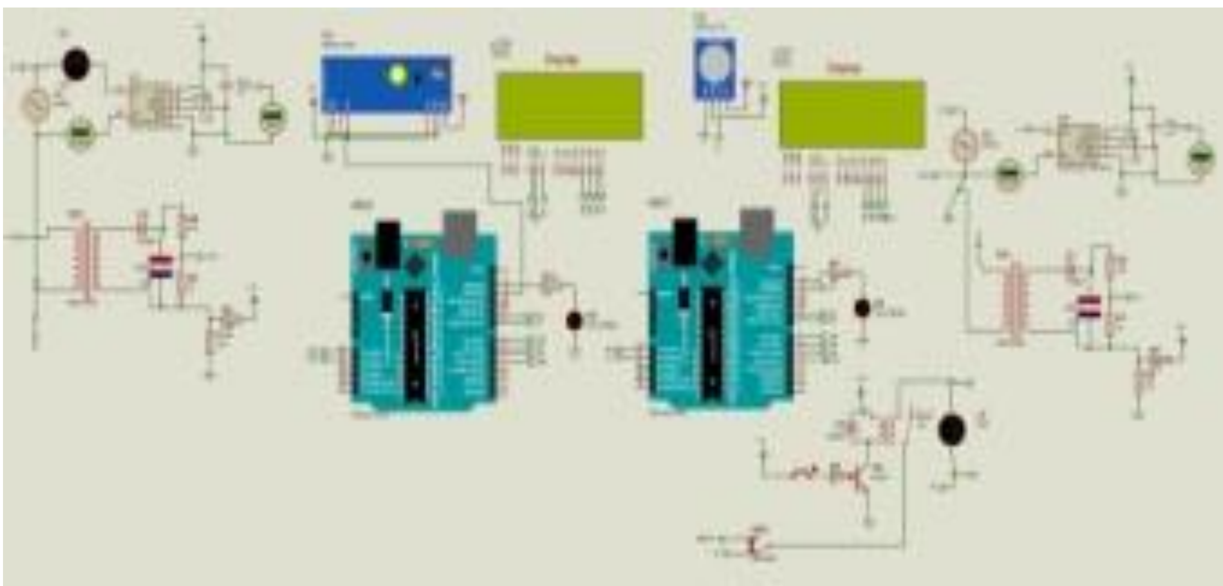

Fig. 10 Simulated circuitry of the energy deterrent system.

5. Conclusion

A smart energy larceny evaluation system incorporating a damping parameter has been proposed to address issues of energy theft. Based on the simulation results from this research, this paper projected the analysis, design and probable challenges presented by the understudy energy theft metering system. Further, the research relevance and improvements on previous work are highlighted. Analysis for investigating the consistency of the model in the presence of damping parameter is shown while the Sensitivity analysis for assessing the dynamic effect of parameters on the damping and power theft function is also considered. The total attained settings are under standard energy metering conditions, the model can dependably estimate critical parameters such as consumed energy, voltage, and current of the load. Finally, the proposed system algorithm is quite satisfactory as it accounts for the accrued energy measurements of all users' meters connected and then utilizes this rate as a reference to detect unmetered load and connections automatically. This reviewed model can enormously reduce the effect of energy theft in distribution system and thus increase energy savings and revenues if adequately implemented.

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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