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Design and Implementation of a Novel Protection Device to Prevent Tampering and Electricity Theft in Commercial Energy Meters

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Abstract—Transmission and distribution losses in a power system are responsible for considerable financial damage. Among the factors associated with these losses electricity theft is of a major concern. Meter tampering is one kind of electricity theft that causes significant revenue losses for the power companies. In this research, a novel protection circuit is designed for conventional analog and digital meters to prevent tampering. The circuit has protection against the common tampering methods like shorting the current coil of the meter, reversing the direction of current flow, disconnecting the neutral line from the meter etc. At first the methods of tampering are described for both analog and digital meters. It is found from the research that though digital meters are better protected than the analog meters it can still be tampered by disconnecting the neutral line. The working principle of the proposed device is described afterwards. Subsequently the paper also illustrates the effectiveness of the device in protecting the meters from common tampering methods. Finally, the financial impacts of this research on the electricity distribution and billing systems are depicted, a few policy implications are drawn considering the impact of the research and some recommendations are also provided for better and efficient utilization of the device.

Index Terms—Meter tampering, CT, Microcontroller, LDR, Revenue loss

1 INTRODUCTION

Energy is an essential ingredient for economic development of a country. It is indispensable for uplifting quality of lifestyle of the general people as well as industrial and agricultural development [1]. Electricity is the most usable form of energy. Most of the energy sources are usually transformed into electricity to the end users. Per capita electricity consumption of a country is often considered as a useful indicator of its socio-economic condition. Bangladesh is a developing nation of South-East Asia with a large population but relatively low income. The per capita electricity consumption in Bangladesh is still very much lower than that of the developed countries [2]. Therefore, it is vital for Bangladesh to utilize its energy resources properly and efficiently. Especially the power sector should be given utmost importance. The power sector of Bangladesh is currently facing some serious problems in order to provide the entire population with adequate power. Gradual depletion of natural gas which is the principal source of energy is one of the main reasons for current power crisis [3]. There are other factors behind the crisis such as lack of sufficient generating stations, continuous operation of several existing power stations beyond their life time, lack of foreign investment, lack of strong administrative and infrastructureal framework, buoreaucratic red tapism, lack of proper policy mechanism for potential energy resources, transmission and distribution losses, insensible use of electricity by individuals, lack of adequate research on alternative sources of energy and efficient energy conversion technology, electricity theft etc. In this paper we have addressed the meter tampering issue which is one form of electricity theft. The conventional energy meters are prone to tampering. We have designed a novlel protection device and implemented in this research to prevent meter tampering and illegal use of electricity. The whole paper is divided into several sections. Firstly, we have described different aspects of energy theft and their consequences. Secondly, we have discussed on the types and working principles of commercial energy meters

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and illustrated the ways of tampering them. Thirdly, we have presented our proposed device and described its working principle. We have also explained the ways with pertinent diagrams how it can provide protection to the conventional meters from tampering. Finally, we have discussed on the potential impact this research may have on ensuring a more efficient and economically productive electricity billing system in Bangladesh.

2 ELECTRICITY THEFT AND ITS DIFFERENT ASPECTS

2.1 TYPES OF THEFT

Electrical power distribution network suffers typically two types of losses: i) Technical loss and ii) Non-technical loss. Technical loss is mainly due to structure and characteristics of the network. Transmission and distribution losses fall into this category. Non-technical losses mainly occur due to electricity theft [4]. Electricity theft comprises of fraudulent activities by the consumer, stealing electricity illegally, irregular billing and unpaid bill [5].

A. FRAUDULENT ACTIONS

Fraudulent actions from the consumers refer to illegally manipulating or tampering the meter by himself or with the help of a professional. By tampering the meter, the reading is usally shown in the meter lower than what it is supposed to be. Large scale meter tamperings were reported in India and Malaysia [5].

B. STEALING ELECTRICITY

Electricity stealing is mainly done by rigging a line from the source of supply. Campbell reported that in 1999, almost 6 tons of cables illegally used for stealing were confiscated by the South African authorities in only 6 months [6]. According to Sullivan, electricity stealing causes loss of revenue amounted almost 475 million US dollar annually in Mexico [7]. However, this practice is more common in South-East Asian nations due to the poor economic condition of the general people [5].

C. IRREGULAR BILL PAYING

Consumers often bribe the meter readers or the concerned officials to reduce their original bill. It is quite a common practice in economically backward countries to underpay the bill with help of the concerned official. This phenomenon mainly occurs where a significant level of corruption is experienced [5].

D. UNPAID BILLS

It is sometimes observed that electricity bills are unpaid due to various reasons. Sometimes an organization may go bankrupt and thus get exemption from paying the due bill. According to Mkhwanazi, it is a common culture in South Africa [8]. Unpaid bills have also been reported in India, Pakistan and Indonesia. In these countries, politically influential persons evade paying for electricity utilizing their influences. Often Government agencies have huge amount of unpaid electric bill as observed in Pakistan. Though some researchers do not put this as a category of electricity theft, Smith argues that it should be considered as a theft when it gets established in an institutionalized form [5]. This practice is even not very uncommon in developed countries as Lundin has reported in the case of USA [9].

2.2 CONSEQUENCES OF ELECTRICITY THEFT

Electricity theft is causing serious economic damage especially to the developing countries [10]. The power utilities incur heavy revenue losses due to theft of electricity [11]. Electricity theft is connected to malgovernance, corruption, poor utility management services, lack of investment and in some cases political intervention. According to Smith, several countries like Bangladesh, Nigeria, Haiti, Albania, Myanmar, Kyrgyz Republic etc. fall into these criteria [5]. Kaufmann et al. showed that transmission-distribution loss and electricity theft are higher in the countries suffering from poor governance and corruption [12]. The economic effect of electricity theft is severe. Due to large losses caused by electricity theft, the power utility companies can rarely are on profit and therefore, they have to raise the electricity charge. This poses pressure on the low income group and creates a general dissatisfaction among the people on the governing authorities. In countries like Bangladesh, where electricity market is a monopoly and the Government has overwhelming control over the market, the Government has to provide power companies heavy subsidy to minimize the losses. This in turn puts the Government under challenge economically. The money provided as subsidy could be invested elsewhere for development purposes.According to Lovei and McKechnie, electricity theft makes the scopes wider for the wealthier and powerful groups of the society to flourish more and more but does not help the poorer section of the society [13]. Therefore, it is essential for any Government to take measures agianst electricity thefts like meter tampering. Smith has prescribed three methods for stopping theft such as: technical/engineering method, managerial method and system change method [5]. In this paper, we have focused on an engineering solution to the meter tampering.

3 COMMERCIAL ENERGY METERS

An electric meter or energy meter is a device that measures the amount of electrical energy consumed by a household, business organization, industry etc. Electric meters are typically calibrated in billing units, the most common one being the kilowatt hour. Periodic readings of electric meters establish billing cycles and energy used during a cycle.There are two types of energy meter commonly used such as 1) Analog meter and 2) Digital meter. In this section, operational principles of these meters and they ways to tamper them are described.

3.1 ANALOG METER

The analog meter operates by counting the revolutions of an aluminum disc which is made to show revolutions proportional to the energy consumption. CT (Current Transformer) measures the phase current (IP) and PT (Potential Transformer) measures the phase voltage to calculate energy consumption. The meter itself consumes a small amount of power, typically around 2 watts for operation.The block diagram of an analog meter is provided in Fig. 1. At normal condition, current flowing from the phase (IP) should be equal to current returning through the neutral (IN).

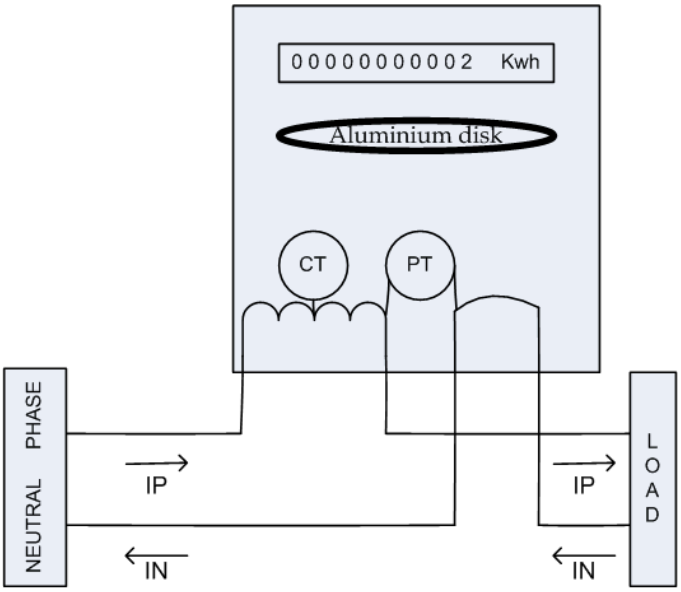

Fig .1 Analog meter

3.2 WAYS TO TAMPER AN ANALOG METER

Tampering meter or fraud contributes to the most part of the losses in electric power distribution sector [14]. It can be done by an individual consumer or an expert professsional. There are several ways to bypass an energy meter [15]. The subsections of this section provide comprehensive illustrations of the ways to tamper the commercial analog meters.

A. SHORTING THE PHASE CURRENT COIL

When, a consumer shorts the current coil of the meter the total current flows through the shorted path, so the meter cannot detect the current flow through it. We know that electrical power is given by the equation, P=VI where P stands for power absorbed or delivered, I for current through and V for voltage across the device. So, if the current coil of the meter is shorted here I=0 ultimately leading to P=0. Therefore, the illegally connected load is not detected by the meter. In Figure 2, the current coil of the meter is shorted and the current through the coil IP2 is zero.

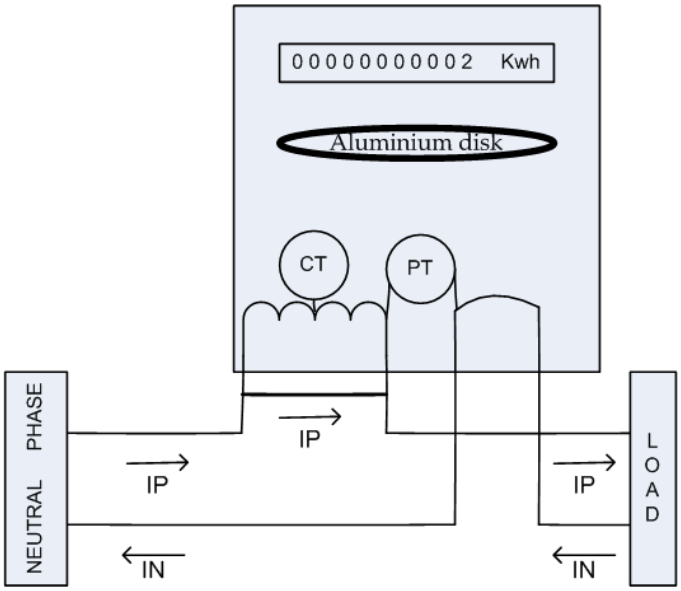

Fig .2 Shorting the phase current coil

B. REVERSING THE DIRECTION OF CURRENT FLOW

If the supply and load positions are swaped as shown in Fig. 3, current flows in reverse direction to the actual current at normal condition. It is experimentally observed that the meter does not respond to reversing the current direction and ultimately behaves as if there is no load connected at all. Therefore, it does not show any energy consumption in the display.

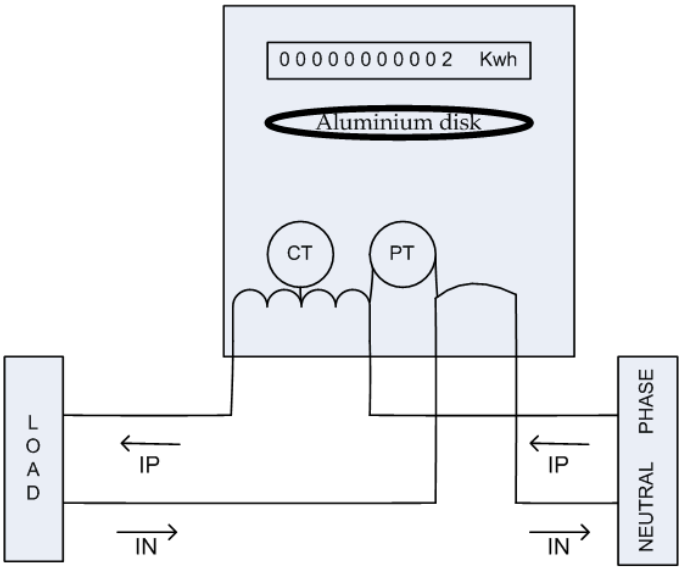

Fig .3 Reverse current flow

C. DISCONNECTING THE NEUTRAL LINE

A more common method of tampering analog meter is disconnecting the neutral line as shown in Fig. 4. In this condition, the meter cannot detect any voltage difference across the supply line and neutral line. As V=0 here, power will be zero by according to P=VI formula. So, no energy consumption will be shown by the meter.

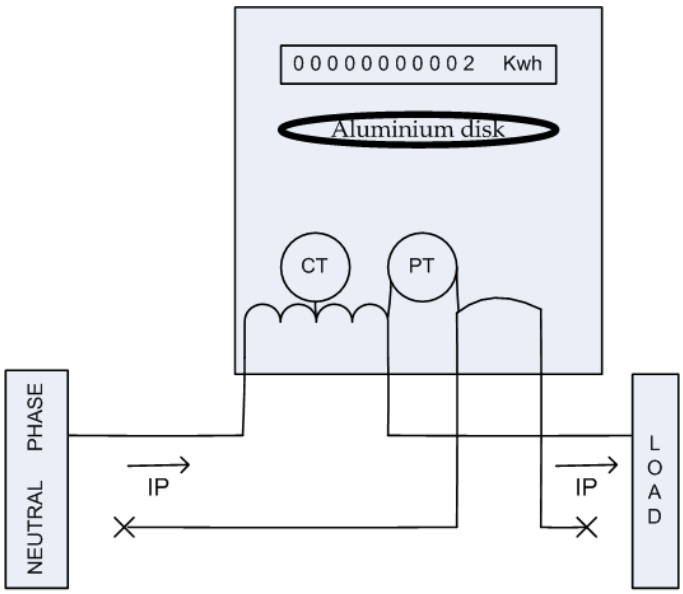

Fig .4 Disconnecting the neutral line

D. TAMPERING USING MAGNET

We know that Aluminium disk is revolving by the magnetic flux produced inside the device due to current flow. If a magnet is kept in the path of this flux, the magnet interferes with the flow of flux. So, the produced flux cannot help the aluminium disk rotate. In this case, the disk is stopped or revolves slower producing less number of revolutions than that it should give. Therefore, accurate energy consumption is not shown in the meter (Fig. 5).

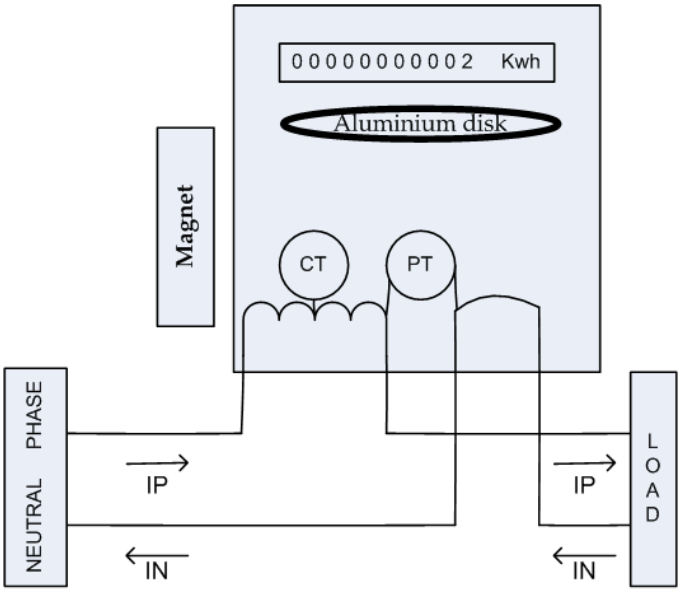

Fig .5 Tampering using magnet

3.3 WORKING PRINCIPLE OF DIGITAL METER

Digital meters are advanced versions of the analog energy meters. They have more protective options than analog meters have. Schematic diagram of a modern digital meter is shown in Fig. 6. It measures both IP and IN. IP is measured by taking the voltage of a shunt resistor connected in series with the line and later converting it to current in the microprocessor unit of the meter. IN is measured by the CT. At normal condition, IP and IN are of equal value. This value along with the phase voltage value from the PT is provided to the microprocessor unit inside the meter to calculate the amount of energy consumed and shown in LCD (Liquid Crystal Display). So, the operation is digital here requiring no rotating disk.

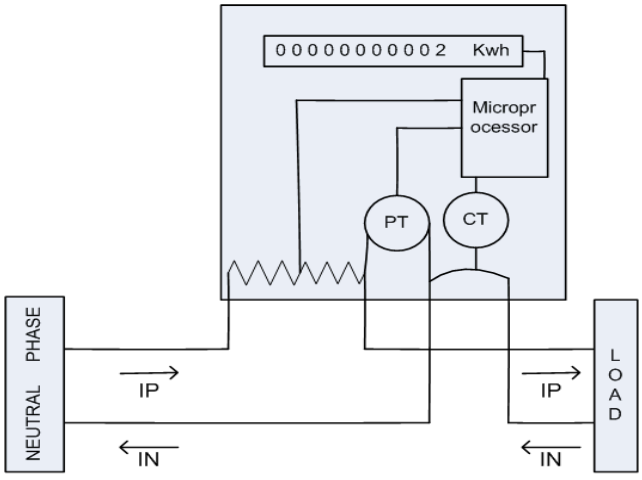

Fig .6 Digital meter

3.4 PROTECTION AGAINST TAMPERING IN DIGITAL METERS

The digital meter is able to protect against tampering methods like reversing the current direction, using magnet and shortingphase current coil. Unlike analog meter it measures both IP and IN. These two values are compared in the microprocessor unit. If these values are found different, the meter detects a possible pilferage. However, it is experimentally found that the digital meter is not able to detect the pilferage when neutral is deliberately disconnected to tamper the meter (Fig. 7).

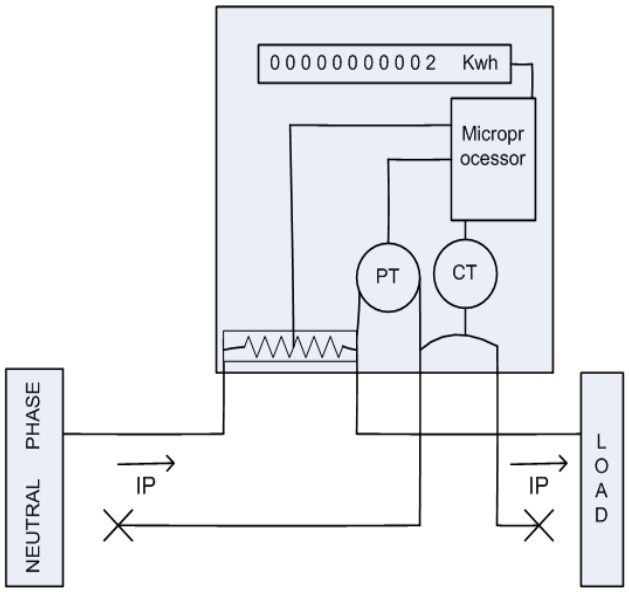

Fig .7 Disconnecting the neutral line

4 THE PROPOSED DEVICE

4.1 WORKING PRINCIPLE

To provide a solution to the problems associated with the commercially available analog and digital meters as mentioned in the previous section, a novel protection circuit is designed in this paper. In this circuit two CTs are used: CT1 in phase line and CT2 in neutral line. CT1 measures IP and CT2 measures IN. These values are provided to the ADC (Analog to Digital Conversion) input of the microcontroller. We have written a program for the microcontroller to compare these two values in C Programing language. If there is any difference between the two values, microcontroller will detect the occurrence of pilferage. The device contains two indicator lights. If microcontroller detects any theft it turns on the red light, otherwise the green light is on. To prevent an analog meter from magnetically tampering, a unique scheme is implemented in the device. Half of the aluminium disk of the analog meter is painted in black and half is kept without any paint. Along with the disk an LED (Light Emitting Diode) and LDR (Light Dependent Resistor) will serve the purpose to prevent magnetic tampering (Fig. 8). The detailed methodology will be described later on.

4.2 ADVANTAGES OF THE PROPOSED DEVICET

This circuit deals with the problems like shorting the phase current coil, reversing the direction of current flow, disconnecting the neutral line and tampering the meter by placing magnet. This section is dedicated to illustrate the major advantages of the proposed circuit over conventional alanog and digital meters (Fig. 8).

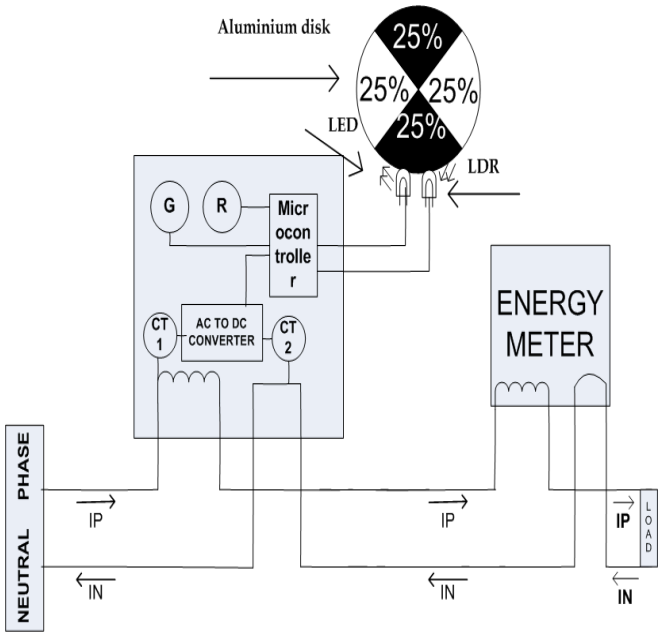

Fig. 8 The proposed device

A. PROTECTION AGAINST SHORTING PHASE CURRENT COIL

In our device we used CT1 in series with the inductor coil in phase side and CT2 in neutral side.If phase coil is shorted, the current flows through the shorted path so the CT1 current is zero but CT2 current is not zero. The device first converts AC to DC voltage then transfers the DC output to the ADC input of the microcontroller. Our device works with the value of the difference between the readings of two CTs. If the difference is a constant, microcontroller detects a possible theft incidence. At normal condition the green light is on. As soon as a theft occurs like phase current shorting the green light is turned off and the red light shines indicating the theft. Even if the shorted path is opened after theft,

the red light will still remain on.

B. PROTECTION AGAINST REVERSING THE CURRENT FLOW

When CT's voltage is converted from AC to DC, CT1 always give positive half cycle in forward or reverse current flow but CT2 give positive half cycle when there is forward current flow and gives zero voltage when there is reverse current flow.Two CT values are transferred to the microcotroler ADC. If the difference value is a constant microcontroller detects theft. Normally here a green light is on when theft occurs microcontroller turns on the red light.

C. PROTECTION AGAINST DISCONNECTING THE NEUTRAL LINE

When the neutral line of the meter is opened with intention to tamper, no current flows through the neutral line.So CT2 has no voltage. But CT1 has voltage. The difference between these two voltages is transferred to the ADC input of microcontroller. If the difference is a constant value microcontroller detects the occurrence of a possible pilferage.Normally the green indicator light is on and upon any occurrence of theft the red light is turned on by the microcontroller.

4.3 PROTECTION AGAINST MAGNITICALLY TAMPERING

We have already mentioned that to protect the analog meter from magnetically tampering we have proposed and implemented a protection scheme in this paper. The aluminium disc of the meter is divided into four sectors each occupying same amount of surface area. Two sectors are painted in black and rests are kept as they were before. Among these four sectors two opposite sectors are of same colour and the other two are without any colour (Fig. 8). In the proposed device an additional LED (Light Emitting Diode) and an LDR (Light Dependent Resistor) were used to prevent magnetic tampering. The LED will always be on and the light will fall upon the disc and the reflected light will be received by the LDR. LDR will convert the received light into electrical voltage and transfer it to the microcontroller. The microcontroller receives the voltage value thereafter. At normal condition, the disc keeps rotating and the LDR output voltage is always changing. If someone attempts to tamper the meter by placing a magnet the received voltage of microcontroller will not change. The disc will not rotate in this case and therefore there will be no change in the voltage from LDR to microcontroller. When microcontroller will not find any change in the voltage from the LDR, it will turn on the red light and indicate the occurence of theft.

5 DISCUSSION

According to a Centre for Policy Dialogue (CPD) report in 1999, the total generated power was 3000 Mega-Watt (MW) in Bangladesh. Distribution loss was much higher than the transmission loss. Total loss of power was about 800 MW which is a monumental figure for a country like Bangladesh. Meter tampering was one the reasons behind this loss [16]. According to another study conducted by Transparency International Bangladesh (TIB) study in April 2005, in a household survey almost 4.3 percent households pay for tampering their meter [17], [18]. So, it is quite clear about the adverse effect electricity thefts like meter tampering have on economy of the country. The device designed and implemented in this paper may be a useful option to combat this problem. Though it can only partially mitigate the problem under discussion, still it will have a significantly positive impact on revenue collection and service of the power utility companies. If revenue collection is increased the utility companies will earn more profit and the Government will have to provide them less subsidy. So, the chance of increasing tariff may possibly be lower than that of now and the Government will have greater opportunity for investing more on the infrastructural development of the power sector. Moreover, the consumers will probably be more sensible using the electricity and thus there will be scope for more people to access electricity.

6 CONCLUSION

In this paper we have focused on a very important aspect of electricity theft which has been a matter of serious concern for the electricity billing and distribution authorities. We have described the different methods of theft along with their adverse financial impacts. It is indeed a very challenging task for the Government to eradicate all kinds of theft regarding electric metering and billing. Nevertheless, this research has provided a technological solution to meter tampering which is a major electricity theft. The proposed device in this paper can be installed as additional equipment with the conventional energy meters to protect the meters from pilferage. The device is commercially viable because of its cost effectiveness. The protoype costs approximately 600 BDT (Bangladesh Taka) which can be further reduced. This device can also be upgraded to an electric energy meter with built in tampering protection. A possible application of this meter can be in the substations to detect energy consumption of unregistered loads. We expect that the device can be a very useful option to stop meter tampering in future.

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