System Design for Prevention of Electricity Theft

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Abstract

This paper describes the effective system developed for the prevention of Electric Power theft caused by direct rigging. The approach used is to make the electricity useless at distribution transformers and to restore the electricity to useful form by passing it through modified Energy Meter which is exclusively responsible for providing useful electricity to genuine consumers. This can be achieved by stepping up voltage by a factor 'k'(where k=2, 3, 4) on low tension side of distribution transformer for short duration in each periodic interval with the help of circuit developed at transformer side. This rough form of voltage if used by direct rigging on electric power conductor, would cause the damage to the appliances. While the genuine consumer gets this supply through modified Energy Meter, which has the ability to detect this rough voltage waveform and convert it back to normal voltage. In this way one of the major causes of electricity theft can be controlled by very economical, simple and technical approach. This circuit has much flexibility in the design so it is less probable to develop a remedy to bypass this design for pilfering.

Index Terms — Direct rigging, distribution transformer, energy meter, electric power conductor.

I. INTRODUCTION

The theft of electric service is an issue that continues to infect utilities across the world. Theft appears in many forms, ranging from sophisticated electronic deception to simply never paying a reasonable bill. As technologies develop to accelerate and improve efficiency of metering and billing, new methods arise to attempt to defraud utilities. Besides the fact that electricity theft is a crime, it also creates an unjustified burden for ratepayers, to whom the cost associated directly with stolen energy and associated revenue protection programs is often distributed. Several reports indicate the prevalence of electricity theft in developing countries range from 20 to 30% losses in the distribution network [1], whereas [2] reported a wider range of 10 - 40% losses. Malaysia In 2004, recorded revenue losses as high as USD229 million and in 2010-11 RM150 to 500 million a year [3-4]. Pakistan has also suffered a mammoth Rs.150 billion loss on account of power theft and line losses in 2012-13[5]. Moreover the developed countries like USA and Canada have also not been spared by this peril and have documented huge revenue loss, that amounts to $6 billion and $100 million, respectively, in 2010 [6-7]. Similarly South Africa documented the revenue loss due to theft of electric power ranging from R2.5 to R3.6 billion per year on average, which in the year 2009 even increased to R4.0 billion [8-9].

A lot of methods have been developed so far to prevent the theft of electricity [10-11]. One good approach is given by [12] which involves measuring the total energy units provided by the distribution transformer and then comparing it with the sum of energy units consumed by each meter, the difference tells about the units lost which may be due to theft or line losses. Another method at [13] uses the power line impedance technique, which involves disconnection of subscribers and then a low voltage signal of 2V at 150Hz is transmitted to the network to detect impedance of the network. This impedance is then compared with the installed impedance values and the difference indicates the theft location with respect to the location of genuine consumer. On the other hand [14] proposes application of smart resistance, incorporated in Smart Meter as a mode of detecting illegal electricity usage. But very less work is available for development of a system which is independent to eradicate the theft of electric power mainly by direct rigging.

It is therefore vital to develop a durable system for prevention of electricity theft. Keeping in view the excessive losses and autonomy requirement, this system has been developed which is self-sufficient to protect against theft of electricity caused by direct rigging.

A.

chematic Diagram of System

The schematic diagram for the implementation of this system is shown in figure 1 below:

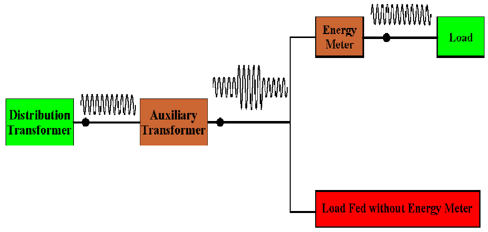


Fig. 1. Schematic Diagram of Design Circuit

It can be seen in the figure 1 that normal voltage supply provided by distribution transformer is disturbed by the auxiliary transformer intermittently, which if fed directly to the equipment, causes damage to its insulation and thus the equipment itself. The over voltage appears for short duration which is customizable e.g. 3 to 5 seconds during 10 minutes interval. Moreover the magnitude of overvoltage is configurable by varying the factor 'k'. This much customization enables to avoid any potential remedy by the thieves of electric power to bypass electricity theft protection system. Therefore the possibility of using this form of power by direct rigging is ruled out. While the same form of power after passing through Energy Meter becomes useful for consumers. As the circuit designed for detecting the disturbed waveform and converting it back to its normal form is implemented in Energy Meter.

This method of disturbing electricity is very clean, flexible and free from any considerable harmonics thus, has no prominent effect on the reliability of power system. Also the components used for designing the circuits are elementary, ensure longer lifespan, and are economical.

II. DESIGN OF CIRCUITS

The design mainly consists of two sections

- Transformer Side Circuit
- Energy Meter Side Circuit

A. *Design of Transformer Side Circuit*

1) Simulation Diagram: Simulation diagram of the circuit which will be explained ahead is shown below:

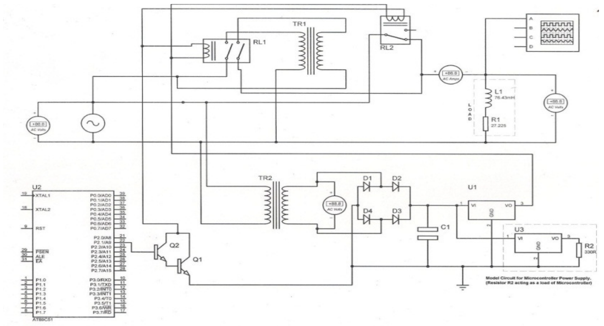


Fig. 2. Circuit Diagram of Distribution Transformer side Section

2) Working Principle: The circuit on transformer side produces the over voltage by switching the primary winding of auxiliary transformer in parallel with a phase of distribution transformer and its secondary in series with load as shown in the figure 3.

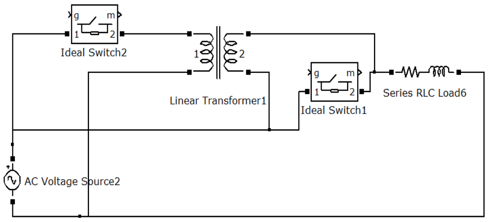


Fig. 3. Simulation for Producing Over Voltages

The circuit on the transformer side consists of only one unit and works for each of the three phases periodically by switching alternatively between the phases and hence minimizing the cost of equipment required.

3) Explanation: The block diagram of transformer side circuit as shown below will be explained ahead. The block diagram comprises of following components:

- Control circuitry
- Switching circuit
- Auxiliary transformer
- AC/DC converter
- Voltage regulators

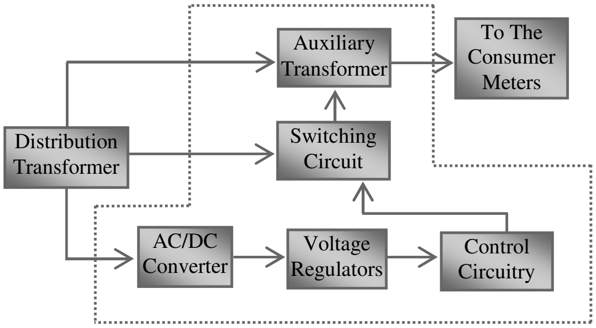


Fig. 4. Block Diagram of Transformer Side Circuit

a) Control Circuitry: This circuitry consists of two main components of which one is microcontroller and second one is Darlington pair. Microcontroller is used here to control the duration of high voltage (440 Volts) pulses. Whereas the Darlington pair is used to amplify the output current from microcontroller in order to feed the appropriate current to switching circuit. Both these circuits are explained below.

(b) Microcontroller: A microcontroller produces periodic pulses to control the over voltage and normal voltage in different intervals of time. This microcontroller gives signal to Darlington pair which in turn makes the relays RL1 and RL2 active or inactive. The relays are fed through voltage regulator U1 as shown in the figure 2.

As the current during the active condition of relays flows through the Darlington pair, which itself draws very small current i.e. µA from microcontroller. Therefor micro-controller is protected against the overloading.

(c) Darlington Pair: Darlington pair draws very small current from microcontroller to drive relays when high input signal is given by microcontroller.

As the current gain of Darlington pair is given as

$$Gain_{DP} = Gain_{Q1} \times Gain_{Q2} \qquad ...(1)$$

$$G_{DP} = G_{Q1} \times G_{Q2} \qquad ...(2)$$

If Q1 and Q2 are identical, then

$$G_{DP} = G_Q^{2} \qquad ...(3)$$

We know that the current gain is

$$G_{DP} = \frac{I_{op}}{I_{in}} \qquad ...(4)$$

$$\frac{I_{op}}{I_{in}} = G_Q^{2} \qquad ...(5)$$

$$I_{op} = G_Q^{2} \times I_{in} \qquad ...(6)$$

For desired output current, input current can be found. In order to limit the input Current to avoid the loading of microcontroller, transistors of high gain should be selected.

(d) *Switching Circuit:* This circuit consists of relays which control the switching of auxiliary transformer and load. The detail of relays is as under:

- (a) *Relays:* When the normal voltage is supplied to load, all the relays are de-energized and the connection of main supply and load is made through normally closed (NC) contact of RL2. When microcontroller gives high signal, both relays are set active. Direct connection of main supply to the load is terminated. At the same time, voltage having value equal to sum of main supply voltage and secondary winding of auxiliary transformer is supplied to the load.
- b) *Auxiliary Transformer:* Auxiliary transformer increases the magnitude of supply voltage by a factor of ‘k’ depending upon its turn ratio. It is switched in the main circuit intermittently to make the electricity unusable. In the figure 2 this transformer is named as TR1.
- c) *AC/DC converter:* AC/DC converter is used here to supply the 12/5 volts DC. 12 volts are supplied to switching circuit and 5 volts to the control circuitry. It consists of following components:
  - i. Potential Transformer TR2: Potential transformer steps down the supply voltage to value required by sensing circuit.
  - ii. Diode Bridge Rectifier: Diode Bridge Rectifier converts ac supply to dc for power supply requirements.
  - iii. Capacitor: Capacitor removes ripples from rectified dc supply to make it smooth and supplies power to voltage regulators.
  - iv. Voltage Regulator: Voltage regulators provide fix dc voltage to the relays for their proper operation. Two voltage regulators (LM7805, LM7812) are used to provide DC voltage to relays and microcontroller.

B. Design of Energy Meter Side Circuit

1) Simulation Diagram: Actual simulation diagram of meter side circuit for single phase is shown in figure 5.

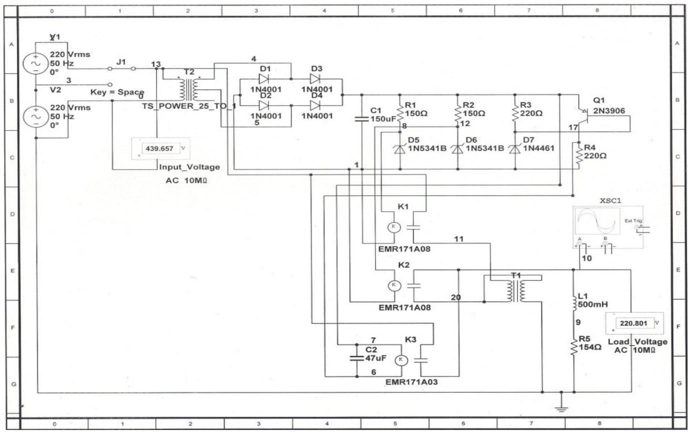


Fig. 5. Simulation Diagram of Meter Side Circuit

2) Working Principle: The circuit on energy meter side works by switching in a step down autotransformer during the period when there is overvoltage detected from transformer side to keep the voltage supplied to the load equal to its nominal value.

The purpose of this circuit is to

- Sense the voltage level of main supply.
- Switch the auto transformer in the circuit in order to provide nominal voltage to the load during over voltage period.
- Switch the auto transformer out of circuit at the end of over voltage period.

3) Explanation: The block diagram of energy meter side circuit as shown in figure 6 will be explained ahead.

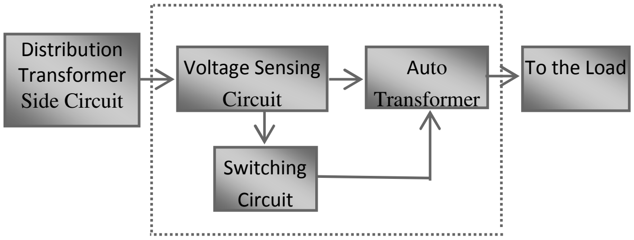


Fig. 6. Block Diagram of Energy Meter Side Circuit

The block diagram comprises of following components:

- Voltage sensing circuit
- Switching circuit
- Autotransformer

a) *Voltage Sensing Circuit:* This circuit is designed such that it gives dc volts analogous to the ac volts at its input side. A transformer, bridge rectifier and capacitor gives DC voltage proportional to AC voltage value of main supply.

This voltage is sensed by Zener regulators. For over voltage, D5 and D6 have greater value of voltage across them, which is enough to turn the relays K1 and K2 ON as shown in the figure 5. These two relays are connected in such a way that the load has nominal value of voltage across it due to step down action of auto transformer.

At the same time, D7 has enough value of voltage to take transistor Q1 in saturation state. As coil of relay K3 is connected to collector and emitter terminals, the only voltage that appears across it will be VEC (sat). This voltage is not enough to operate Relay contact K3. Thus during the over voltage period, K3 is kept de-energized.

In order to ensure proper operation of voltage sensing circuit, first it would be evaluated at over voltage and normal voltage conditions:

(a) *Over Voltage Calculation*: Let L1 be the coil of relay connected in parallel with D1 Zener diode, as shown in the figure 7, and V_{Pull} be the voltage required to operate relay then,

$$V_{in} = I_{in}R_{in} + V_{out} \quad \text{...(7)}$$

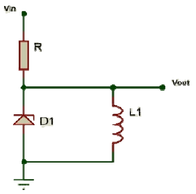


Fig. 7. Zener Voltage Regulator

Current I_K through relay coil will be

$$I_K = \frac{V_{Pull}}{R_K} \quad \text{...(8)}$$

Here R_K is the resistance of the coil.

Now the current I_{in} through the resistor R will be

$$I_{in} = I_{z\,(min)} + I_K \quad \text{...(9)}$$

Here $I_{z\,(min)}$ is current through Zener diode determined practically.

During over voltage condition the voltage across the resistance and zener diode in figure 7 will be

$$V_{in\,(min)} = I_{in}R_{in} + V_{out} \quad \text{...(10)}$$

Substituting value of I_{in} from equation 9 to equation 10, we have

$$V_{in\,(min)} = [(I]_{z\,(min)} + I_K)R_{in} + V_{out} \quad \text{...(11)}$$

If the ripple factor is r , then the ripple voltage V_r will be

$$V_r = V_{in(min)} \times r \quad \text{...(12)}$$

And the peak value of ripple voltage V_{rp} will be

$$V_{rp} = \sqrt{2} \times V_{in(min)} \times r \quad \text{...(13)}$$

The peak value of input voltage will be

$$V_{in\,(over)} = V_{in\,(min)} + V_{rp} \quad \text{...(14)}$$

The current through R3, in figure 5, will be

$$I_{R3} = \frac{8.4 - V_{z\,(D7)}}{R_3} \quad \text{...(15)}$$

The current passing through transistor Q1 will be

$$I_{Q1} = \frac{8.4 - V_{EC\,(SAT)}}{R_4} \quad \text{...(16)}$$

Here $V_{in(min)} = 8.4V$. During the over voltage, the maximum current I_{ov} drawn from supply will be

$$I_{ov} = I_{R1} + I_{R2} + I_{R3} + I_{Q1} \quad \text{...(17)}$$

Here $I_{in} = I_{R1} = I_{R2}$.

(a) Normal Voltage Calculation: *Let the over voltage* $= y \times V_p$

Where y is the factor by which over voltage will be generated and depends upon the ratio of auto transformer.

If auto transformer ratio is 1:1, then y =2. If it is 1:2, then y =3 and so on.

At normal voltage supply, voltage across capacitor will be reduced by a factor of z i.e.

$$V_c = \frac{V_{in\,(over)}}{z} \quad \text{...(18)}$$

If z = 2, then

$$V_{in\,(normal)} = \frac{V_{in\,(over)}}{2} \quad \text{...(19)}$$

Let under normal condition of supply voltage, the voltages across Zener diodes and transistor are $V_{ZD5\,(normal)}$, $V_{ZD6\,(normal)}$, $V_{ZD7\,(normal)}$ and $V_{EC\,(normal)}$.

Now currents through R$_1$, R$_2$, R$_3$ and Q$_1$ will be determined by the following equations

$$I_{R1} = \frac{V_{in\,(normal)} - V_{ZD5\,(normal)}}{R_1} \quad \text{...(20)}$$

$$I_{R2} = \frac{V_{in\,(normal)} - V_{ZD6\,(normal)}}{R_2} \quad \text{...(21)}$$

$$I_{R3} = \frac{V_{in\,(normal)} - V_{ZD7\,(normal)}}{R_3} \quad \text{...(22)}$$

$$I_{Q1} = \frac{V_{in\,(normal)} - V_{EC\,(normal)}}{R_4} \quad \text{...(23)}$$

During the normal voltage, the maximum current drawn I_{nv} will be

$$I_t = I_{R1} + I_{R2} + I_{R3} + I_{Q1} \quad \text{...(24)}$$

When transition occurs from over voltage to normal voltage, voltage across capacitor varies from $V_{in\,(normal)}$ to $V_{in\,(min)}$. For a continuous supply to load, time of this transition must be short enough to avoid low voltage to load. During this transition, current is provided by the capacitor only (due to reverse biased diodes).

Current supplied to the rest of the circuit by the capacitor also varies as the voltage across capacitor drops from $V_{in\,(normal)}$ to $V_{in\,(min)}$, and the variation of current will be from I_{ov} to I_t.

As we know that

$$I = C\frac{dv}{dt} \quad \text{...(25)}$$

Here for the sake of simplicity, we take the average value of currents I_{ov} and I_t.

$$I_{avg} = \frac{I_{ov} + I_t}{2} \qquad \text{...(26)}$$

And

$$C = I_{avg} \frac{dt}{dv} \qquad \text{...(27)}$$

If the transient time is limited to 15 milliseconds, and the change in voltage is 5V, then approximate value of Capacitor will be

$$C = I_{avg} \frac{15m}{5} \qquad \text{...(28)}$$

$$C = 3I_{avg} \times 10^{-3} F \qquad \text{...(29)}$$

This sensing circuit has following components:

- AC/DC Converter
- Zener Diodes

(b) AC/DC Converter: AC/DC converter is used in meter side circuit to provide appropriate dc voltage to Zener diode, so that Zener could detect the voltage level. It has following components:

(i) Potential Transformer: The potential transformer steps down the nominal ac voltage to permissible lower voltage, so that this lower voltage can further be used for conversion into DC by using bridge rectifier.

Now, as maximum current drawn by the sensing circuit is during the overvoltage condition i.e. $\mathbf{I_{ov}}$

So load Resistance for capacitor will be

$$R_L = \frac{V_{in\,(min)}}{I_{ov}}\ \Omega \qquad \text{...(30)}$$

To find the value of ripple factor r we use the following relationship for 50 Hz

$$r = \frac{2887}{R_L C} \qquad \text{...(31)}$$

For excellent power supply ripple voltage must be less than the 5% [15].

So,

$$r = 5\% = 0.05$$

$$V_r = V_{in(over)} \times r \qquad \text{...(32)}$$

And the peak value of ripple voltage

$$V_{rp} = \sqrt{2} \times V_{in\,(over)} \times r \qquad \text{...(33)}$$

The peak value of input voltage will be

$$V_{ac(peak)} = V_{in\,(over)} + V_{rp} + 2V_D \qquad \text{...(34)}$$

Here V_D is voltage drop across single diode.

The RMS value of ac voltage can be found by

$$V_{ac\,(rms)} = \frac{V_{ac(peak)}}{\sqrt{2}} \qquad \text{...(35)}$$

And the current rating of transformer will be

Hence

$$I_{ac\,(rms)} = \frac{I_{ov}}{\sqrt{2}} \qquad \text{...(36)}$$

Due to use of bridge diode rectifier, the transformer utilization factor becomes 81% [16].

So VA rating of potential transformer will be

$$VA\ rating\ of\ potential\ transformer \qquad \text{...(}$$

$$= \frac{[(I]_{ac\,(rms)} \times V_{ac\,(rms)})}{0}.81$$

$$VA\ rating\ of\ potential\ transformer \qquad \text{...(}$$

$$= 1.23\,(\,I_{\downarrow}(ac\,(rms))\,) \times V_{\downarrow}(ac\,(rms))\ )$$

(ii) Diode Bridge Rectifier: Diode Bridge Rectifier converts ac voltage to dc for power supply requirements.

(iii) Capacitor: Capacitor removes ripples from rectified dc supply to make it smooth. The value of capacitor C_1 as shown in figure 5 should be large enough so that it can provide DC voltage to the Zener regulator. But at the same time it should not be very large to cause unnecessary time delay during the transition of voltages.

(c) Zener Diodes: Zener diodes are used here for sensing purpose. They have specific DC voltage across them during the normal and overvoltage AC conditions, which help them to energize or de-energize the coils of relays as required.

b) Switching Circuit*: it consists of three relays K1, K2 and K3 as shown in figure 5. Its operation depends upon the dc voltage supplied by the sensing circuit to the relay coils.*

During normal voltage level of main supply the voltage across D5, D6 and D7 will not be able to operate the relays K1 and K2. So the relays K1 and K2 will remain de-energized and the auto transformer is out of the circuit. At the same time, the transistor Q1 gets out of saturation state and V_{EC} will become large enough to operate K3. As a result K3 makes the direct connection of the load with the main supply.

The calculation of overvoltage and under voltage for relays K1 and K2 have already been discussed under the section of voltage sensing circuit.

c) Autotransformer: The purpose of autotransformer is to step down the voltage during over voltage condition to provide nominal voltage to the load (domestic consumer) uninterruptedly. Auto transformer must have turn ratio of (1/y) in order to provide nominal voltage to the load. As KVA for each Domestic connection is selected as 6 KVA, so required KVA rating of auto transformer will be (6KVA/y) [17].

As the auto transformer will be used for short period of time so the required KVA for auto transformer will be reduced by a factor specified by the manufacturer.

If reduction factor is ‘L’, then

VA rating required for auto transformer = L(6KVA/y)
Where L is less than or equal to unity.

III. MODIFICATION IN DESIGN

The voltage sensing circuit on meter side has been designed for voltage variation of 200V to 320V. In Pakistan sometimes voltage drops up to 160V in some areas due to long length of feeders. In order for the circuit to work in this condition, there are two solutions.

4) Redesign the Circuit: Redesign the complete circuit for minimum voltage level of 160V. In this method all parameters of the circuit will have to be designed according to the requirement.

5) Change the Turn Ratio of Potential Transformer: Increase the sensing voltage by increasing the turn ratio of potential transformer in order to step up the voltage to a value required by the sensing circuit. The ratio of transformer selected for minimum voltage i.e. 200V of design is 50:1

For 200V secondary voltage will be

$$V_{sec} = \frac{200}{50} = 4V$$

For 160V secondary voltage must also be 4V for proper working of sensing circuit. Turn ratio can be calculated as

$$V_{sec} = 4V$$

$$V_{sec} = \frac{160}{n}$$

$$n = \frac{160}{V_{sec}}$$

$$n = \frac{160}{4} = 40 \ turns$$

So the turn ratio should be 40:1 for 160V input.

IV. FINAL FABRICATED PROTOTYPE CIRCUITS

The proposed system was not only simulated using MATLAB, NI Multisim 10, Keil µVision 3 and Proteus 7.6 Professional, but also fabricated. The final outlook of the circuits is shown in the pictures below:

Fig. 8. Exterior View of Fabricated Circuits

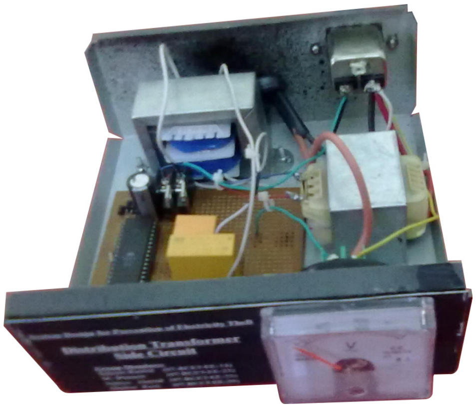


Fig. 9. Interior View of Transformer side Circuit

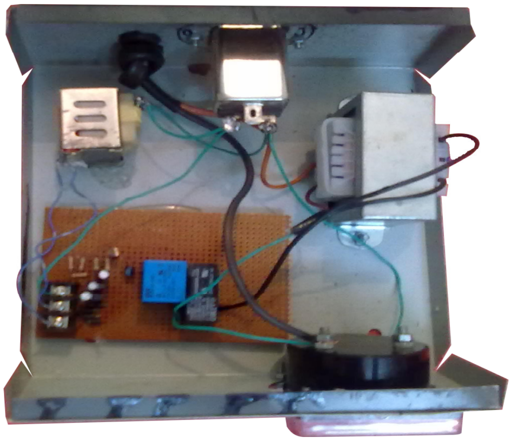


Fig. 10. Interior View of Meter side Circuit

V. CONCLUSION

a. Cost/Benefit Ratio

Cost to benefit ratio is calculated in order to estimate the value of practical implementation of the project. In this report, cost to benefit ratio has been calculated for Peshawar Electric Supply Company (PESCO) in order to indicate the importance of project.

I) *PESCO Cost to Benefit Ratio Analysis:*

The cost to benefit ratio has been calculated for domestic, commercial and agricultural customers as follows.

From [18] the sum of the above mentioned consumers is given as

$$Total\ number\ of\ consumers = 2564498$$

a) Energy Meter Circuit Cost

TABLE I. ENERGY METER CIRCUIT COST

Sr. No.	Components	Cost (Rs.)
1.	Potential Transformer (PT)	50
2.	Diodes	8
3.	Capacitor	6
4.	Resistor	2
5.	Zener Diode	12
6.	Transistor	2
7.	Relays	140*3 = 420
8.	Autotransformer	375
9.	Circuit Manufacturing Cost	50
Total cost		**925**

$$Cost\ of\ single\ meter\ circuit\ with\ 20\ \%\ margin$$

$$= 925 + \left(\frac{20}{100} \times 925\right)$$

$$= Rs.1110$$

b) Transformer Circuit Cost

TABLE II. TRANSFORMER CIRCUIT COST

Sr. No.	Components	Cost (Rs.)
1.	Relays	500
2.	Potential Transformer (PT)	150
3.	Diodes	8
4.	Capacitor	10
5.	Transistor	4
6.	Voltage Regulators	10
7.	Microcontroller	70
8.	Auxiliary Transformer	4900
9.	Manufacturing Cost	400
10.	Installation Cost	5000
Total cost		**11052**

$$Total\ cost\ of\ Transformer\ circuit\ with$$

$$20\%\ safety\ margin = 11052 + ((0.2)(11052))$$

$$= Rs.13263$$

$$Total\ cost\ for\ considered\ consumers\ (Meters) = \left(\begin{matrix}Total\ number\ of\\ consumers\end{matrix}\right)\left(\begin{matrix}Cost\ of\ single\\ meter\ circuit\end{matrix}\right)$$

$$= (2564498)(1110)$$

$$= Rs.2846592780$$

Similarly, the cost for the total transformer circuits installed can be calculated as

$$Total\ cost\ for\ Transformer\ circuits = \left(\begin{matrix}Total\ number\ of\\ Transformer\ circuits\end{matrix}\right)\left(\begin{matrix}Cost\ of\ single\\ Transformer\ circuit\end{matrix}\right)$$

Where

$$Total\ number\ of\ transformer\ circuits = \frac{Total\ number\ of\ consumers}{Number\ of\ consumers\ per\ transformer}$$

$$= \frac{2564498}{20}$$

$$= 128225$$

Hence

$$Cost\ for\ total\ Transformer\ Circuits$$

$$= (128225)(13263)$$

$$= Rs.1700648175$$

Now the Grand total of cost is given as

$$= (Total\ cost\ for\ Transformer\ circuits) + (Total\ cost\ for\ considered\ consumers\ (meters))$$

$$Grand\ Total = Rs.4547240955$$

The following data for losses is collected for ten months.

Now the total losses will be calculated as follows,

$$Total\ units\ generated\ in\ PESCO = 9483.06\ GWh$$

$$Units\ billed = 6307.31\ GWh$$

$$Total\ units\ lost = 3175.75\ GWh$$

$$So, the\ losses\ in\ percentage\ are = 33.5\ \%$$

Now, the actual losses of 3.5% will be subtracted from total losses to get the theft losses. [18]

$$Total\ theft\ losses = (3175.75)(1 - 0.035)$$

$$= 3064.6\ GWh$$

$$= 3.0646 \times 10^{9}\ KWh$$

If the cost per unit (KWh) is Rs. 10 then

$$Total\ revenue\ lost\ due\ to\ theft = (3.0646 \times 10^{9}\ KWh)(10$$

$$= Rs.3.0646 \times 10^{10}$$

This is loss for ten months, and then loss for a year will be calculated as,

$$Total\ revenue\ lost\ due\ to\ theft\ per\ year = \left(\frac{3.0646 \times 10^{10}}{10}\right)(12)$$

$$= Rs.3.67752 \times 10^{10}$$

Since the component having minimum life used in the circuit is relay that has life span of 10^6 number of operations (available in the market). The relay operates ones a ten minutes, it will operate 144 times a day. So the number of relay operations in a year will be,

$$144 \times 30 \times 12 = 51840$$

Hence the total life of a relay and the circuit will be,

$$\frac{10^6}{51840} = 19\ years$$

Considering safety margin, it is assumed that relay has a life span of 15 years for this project.

Now,

Total revenue loss due to theft for 15 years $= Total\ revenue\ lost\ per\ year \times 15$

$$= (3.67752 \times 10^{10})(15)$$

$$= Rs.5.51628 \times 10^{11}$$

This revenue loss can be recovered as a benefit if the designed circuit is implemented.

Hence,

$$Cost\ to\ benefit\ ratio = \left(\frac{4547240955}{5.51628 \times 10^{11}}\right)$$

$$Cost\ to\ benefit\ ratio = 0.00824$$

6) Calculation for the Recovery Period of Initial Cost: This calculation gives the time period in which this project will recover its initial cost after its implementation. First of all monthly loss will be calculated then total cost will be divided by this monthly loss to get the recovery period in months.

$$Monthly\ loss = \frac{Total\ revenue\ lost\ due\ to\ theft\ in\ 15\ year}{15 \times 12}$$

$$Monthly\ loss = \frac{5.51628 \times 10^{11}}{15 \times 12}$$

$$Monthly\ loss = Rs.3.0646 \times 10^9$$ Hence,

$$Recovery\ Period = \frac{Grand\ Total\ of\ initial\ cost}{Monthly\ loss}$$

$$Recovery\ Period = \frac{4547240955}{3.0646 \times 10^9}$$

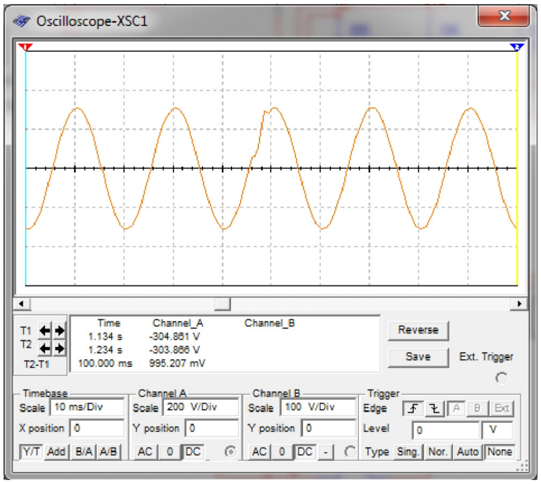
$$Recovery\ Period = 1.48\ months \approx 1.5\ months$$

So the circuit's initial cost will be recovered in almost 45 days.

B. Results

In this Project the goal was to make the distribution system efficient enough to prevent theft of electricity. Distribution Loss due to theft is one of the major reasons of developing the gap between supply and demand of electrical energy in Pakistan. This project addresses precisely the same problem with appropriate solution.

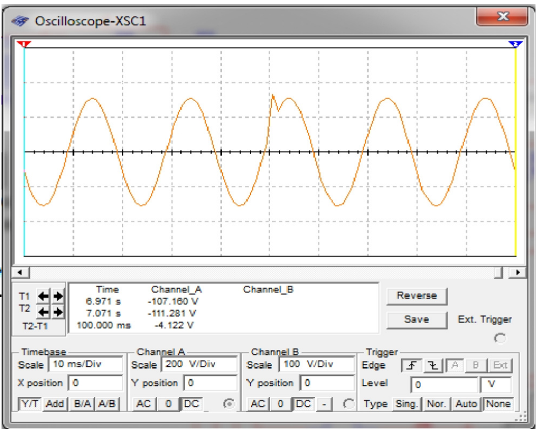
Following are the actual results for the waveforms at the output of the energy meter side circuit when the output of distribution transformer side circuit changes from normal to overvoltage and overvoltage to normal. These waveforms are obtained by the simulation performed in NI Multisim 10.0 and Proteus 7.6 Professional.



	Time	Channel_A	Channel_B
T1	1.134 s	-304.861 V	
T2	1.234 s	-303.866 V	
T2-T1	100.000 ms	995.207 mV	

Timebase: Scale 10 ms/Div; X position 0
Channel A: Scale 200 V/Div; Y position 0
Channel B: Scale 100 V/Div; Y position 0
Trigger: Level 0 V

Fig. 11. Output of Energy Meter Side Circuit during Normal Voltage to Overvoltage Transition at the Output of Transformer Side Circuit.



	Time	Channel_A	Channel_B
T1	6.971 s	-107.160 V	
T2	7.071 s	-111.281 V	
T2-T1	100.000 ms	-4.122 V	

Timebase: Scale 10 ms/Div; X position 0
Channel A: Scale 200 V/Div; Y position 0
Channel B: Scale 100 V/Div; Y position 0
Trigger: Level 0 V

Fig. 12. Output of Energy Meter Side Circuit during Overvoltage to Normal Voltage Transition at the Output of Distribution Transformer Side Circuit.

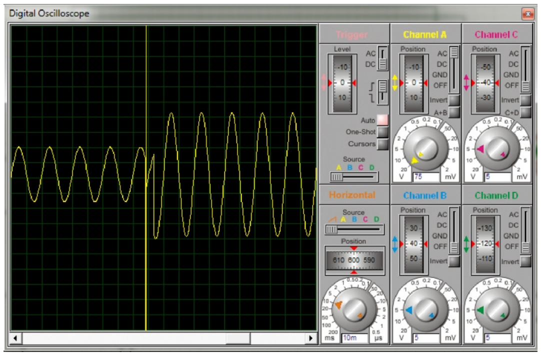


Fig. 13. Normal Voltage to Overvoltage Transition at the Output of Distribution Transformer Side Circuit.

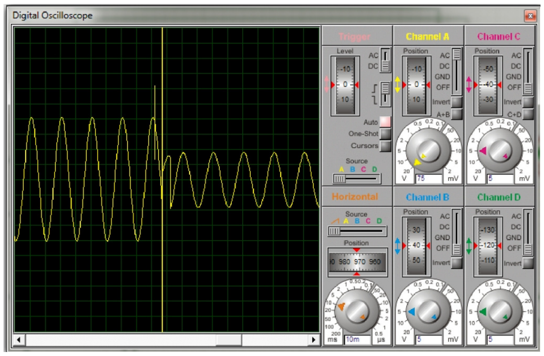


Fig. 14. Overvoltage to Normal Voltage Transition at the Output of Distribution Transformer Side Circuit.

This project has the following major Benefits in it:

- Flexible Solution
- Cost Effective
- No Human Intervention

i) *Flexible Solution:* The solution is not only unique but also flexible in the manner that switching intervals and pulse voltage magnitude are customizable, which provides protection against design theft.

ii) *Cost Effective:* The design is also cost effective as depicted by the cost to benefit ratio (cost recovers in almost 45 days) results.

iii) *No Human Intervention:* The circuit makes the distribution system self-efficient to avoid theft of electricity. Hence the human intervention (Line-men, meter reader) is no more encountered.

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