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Analysis of losses in power system and its economic consequences in power sector

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Abstract: Power system losses can be divided into two categories: technical losses and non-technical losses. Technical losses are naturally occurring losses (caused by actions internal to the power system) and consist mainly of power dissipation in electrical system components such as transmission lines, power transformers, measurement systems, etc. Technical losses result from the impedance of the network components such as electric lines/ cables, transformers, metering and protecting equipment etc. Non-technical losses, on the other hand, are caused by theft, metering inaccuracies. The distribution system accounts for highest technical and non technical losses in the power system. The transmission and distribution losses in our country, which were around 15% up to 1968, increased gradually to 30% by 2012-13. Simply Electricity losses are defined as the difference between quantities of electricity delivered and quantities of electricity recorded as sold to customers. The purpose of this paper is to analyze Technical and Non Technical Losses and its economic consequences in power sector with the help of a case study and MATLAB Simulation in power systems.

Keywords: Economic consequences, Electricity Act-2003, Non Technical Losses & Technical Losses.

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1. Introduction

Percentage of transmission and distribution losses in India is quite high. Distribution losses are defined as the difference between quantities of electricity delivered and quantities of electricity recorded as sold to customers. Distribution losses are of two types: Technical losses and Non-Technical losses. The Distribution losses in the advanced Countries of the world ranging from 4-12%, but in India they reached up to 30% [1,2]. Distribution losses in India are not comparable with advanced countries as the system operating conditions are different in different countries.

2. Analysis of Technical losses in power systems

Technical losses result from equipment inefficiency, the inherent characteristics of the materials used in the lines and equipment, and the sizes of lines and equipment. The three major contributors are the current squared losses through a resistance, transformer excitation losses, and line and insulation corona or leakage losses [3]. In AC systems the copper losses are higher due to skin effect. Due to skin effect, the flux density at the centre of the conductor is great and current flow towards the surface of the conductor is greater. Therefore the skin effect increases the resistance and thus the power loss. The increase in resistance is proportional to the frequency of the AC signal. Transformer losses include copper losses due to the internal impedance of transformer coils and core loss. Power transformers are connected permanently to the power system; hence their no-load losses have to be considered. No-load losses are a function of the type of lamination, core material, insulation, voltage and frequency. The most predominant no-load losses are the core losses, made up of hysteresis and eddy current losses, expressed by the equations:

Hysteresis loss, $P_H = K_h f B_m$

Eddy Current Loss, $P_E = K_e f^2 B_m^2$

where,

f = frequency,

B_m = flux density of the core material,

K_h, K_e = Hysteresis & Eddy current constant, Dielectric losses are losses that result from the heating effect on the dielectric material between conductors. The heat produced is dissipated in the surrounding medium. Induction and radiation losses are produced by the electromagnetic fields surrounding conductors. Induction losses occur when the electromagnetic field about a conductor links another line or metallic object and current is induced in the object. As a result, power is dissipated in the object and lost [4]. Radiation losses occur because some magnetic lines of force about a conductor do not return to the conductor when the cycle alternates. These lines of force are projected into space as radiation and these results in power losses, that is, power is supplied by the source, but is not available to the load.

3. Analysis of Non Technical losses in Power System

NTLs, by contrast, relate mainly to power theft in one form or another. They are related to the Customer management process and can include a number of means of consciously defrauding the utility concerned [5]. By default, the electrical energy generated should equal the energy registered as consumed. However, in reality, the situation is different because losses occur as an integral result of energy transmission and distribution.

Energy Losses

$E_{Loss} = E_{Delivered} - E_{Sold}$

Revenue Loss due to technical losses

$C_{Com\ Loss} = U_{Elect\ Cost} \times E_{Loss} + M_{Maintenance\ Cost}$

Non-technical Loss

$C_{NTL} = C_{Com\ Loss} - C_{Technical\ Loss}$

where,

$U_{Elect\ Cost}$= Unit cost of electricity

The information about the power sources and loads are needed to determine expected losses in the power system using load-flow analysis software. The actual losses are the difference between outgoing energy recorded by the source (e.g., at a substation) and energy consumed by the consumers, which is shown on the bills. The discrepancy between expected losses and actual losses would yield the extent of nontechnical losses in that system.

Technical losses will be simply calculated using load flow method of power system. This will be done because non technical losses are more difficult to measure. As NTL cannot be computed and measured easily, but it can be estimated from preliminary results, i.e. the result of technical losses are first computed and subtracted from the total losses to obtain the balance as NTL [6]. The technical losses are computed using appropriate load-flow studies simulated under MAT LAB environment

Consider the transmission line length to be 3 km. The following are the specifications of a simple two bus system which is needed to complete a load-flow calculation for power loss in the transmission line are given below:

Base Values: 11000 Volts, 100 Ampere, 1.1 MVA, 110 Ohms

Transmission Line Resistance = 3 km × 0.266432 Ohms/conductor/km ×3 conductors

= 2.3978 Ω

= 0.021799 p. u.

Transmission Line Reactance = 3 km × 0.348692 Ohms/cond./km × 3 conductors

= 3.1382 Ω

= 0.028529 p. u.

The following are the load profiles of a simple industrial load and a residential load. The load is shown in kVA with the power factor calculated for each hour.

Table: 3.1 Load profiles for Industrial and Residential load

Time (Hrs.)	Industrial load (kVA)	Power factor of load 1	Residential load (kVA)	Power factor of load 2
1	65	0.92	32	0.82
2	70	0.92	30	0.82
3	88	0.92	50	0.82
4	87	0.87	38	0.87
5	92	0.90	25	0.85
6	102	0.91	42	0.77
7	120	0.87	83	0.72
8	150	0.82	75	0.74
9	230	0.77	100	0.79
10	235	0.77	62	0.83
11	255	0.77	50	0.85
12	265	0.77	57	0.81
13	275	0.77	30	0.80
14	300	0.77	60	0.85
15	300	0.77	45	0.88
16	300	0.82	59	0.79
17	250	0.82	90	0.75
18	175	0.82	100	0.71
19	135	0.87	130	0.73
20	90	0.90	150	0.70
21	85	0.91	175	0.79
22	70	0.92	82	0.80
23	65	0.91	73	0.84
24	60	0.91	65	0.91

A load profile of 24 hours has been shown for simplicity and the further calculations have been done with the help of Newton-Raphson method. Figure: shows the variation of the loads during 24 hours.

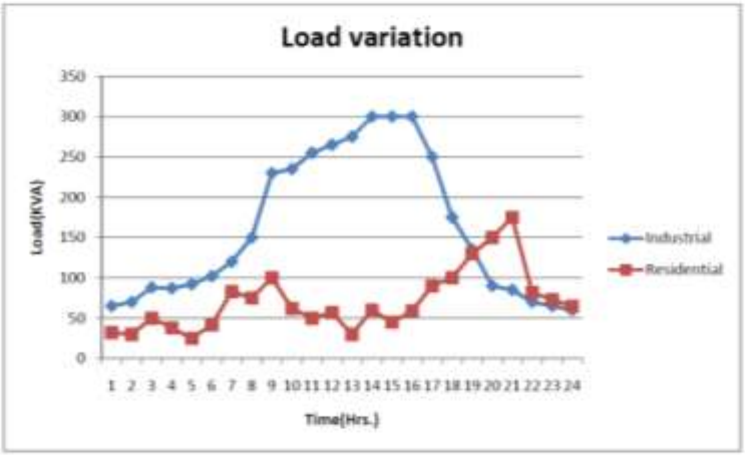

Fig 3.1 Load variations over 24 hour

Figure: 3.1 shows the industrial load has its peak demand during day times and the residential load demand is more during morning and evening hours. The load peaks are at 300 kVA for load1 and 175 kVA for load 2. The average load demands (sum of peak values / no. of hours in a day) are 161 kVA and 70.95 kVA for load 1 and load 2, respectively (Load 1= Industrial, Load 2= Residential). Load power factors are shown in Figure:3.2 below. Thus there are variations in load and power factor over 24 hours.

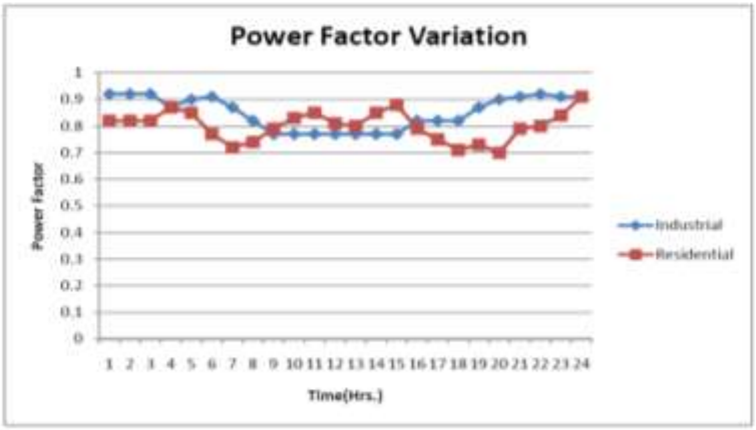

Fig 3.2 Variation of power factor over 24 hours

4. Addition of Non Technical Losses

As shown in the case study, non technical losses are not easy to calculate because it contains a major portion of transmission & distribution losses. Non-technical losses can also be viewed as undetected load of customers that the utilities don’t know. When an undetected load is attached to the system, the actual losses increase while the losses expected by the utilities will remain the same [7]. The increased losses will show on the utilities’ accounts, and the costs will be passed along to the customers as transmission and distribution charges. From the various studies, it has been concluded that NTL constitutes 2-3% of the total system losses. Thus calculations have been shown by adding 3% of the original kVA demand to one of the bus and the modified results have been shown using Matlab simulation. Hence the total increase in losses has been calculated. From the technical loss analysis above, the effects of an undetected load attached to one of the buses in the two-bus test system can be measured by adding 3% extra demand values to one of the loads and evaluating the changed losses.

Table: 4.1 Extra load profile with negative power factor addition

Time (Hrs.)	NTL Load (kVA) added at Bus 2	NTL Load power factor
1	2.91	-0.0246
2	3.00	-0.0246
3	4.14	-0.0246
4	3.75	-0.0261
5	3.51	-0.0255
6	4.32	-0.0231
7	6.09	-0.0216
8	6.75	-0.0222
9	9.90	-0.0237
10	8.91	-0.0249
11	9.15	-0.0255
12	9.66	-0.0243
13	9.15	-0.0240
14	10.80	-0.0255
15	10.35	-0.0264
16	10.77	-0.0237
17	10.20	-0.0225
18	8.25	-0.0213
19	7.95	-0.0219
20	7.20	-0.0210
21	7.80	-0.0237
22	4.56	-0.0240
23	4.14	-0.0252
24	3.75	-0.0273

The power factor contributions chosen here are negative because the NTL load is assumed to be Inductive, i.e., motors or light fixtures. The extra load and negative power factor addition to second bus are shown in the Figures 4.1 and Figure 4.2 respectively.

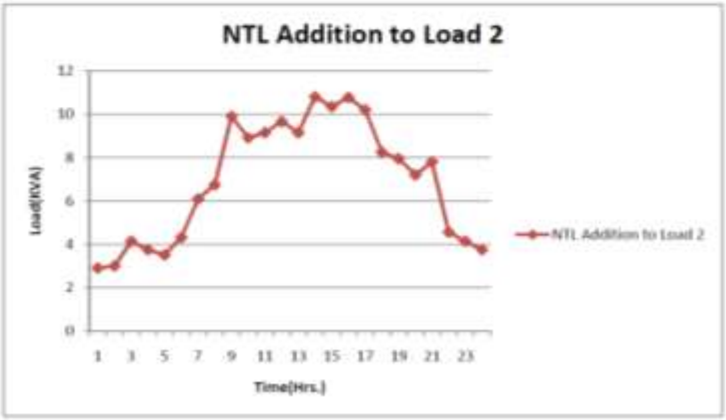

Figure 4.1 NTL addition

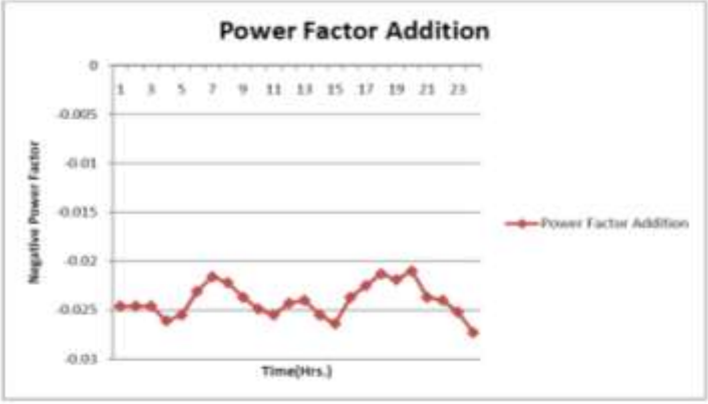

Fig 4.2 Power factor additions

The simulation is run with bus 1 as the slack bus. The NTL power factor contribution is negative at all times because the NTL load is assumed to be inductive. After the simulation was completed and evaluated, some notable results were evident. The Active & Reactive power losses along with NTL in transmission line are shown in Figures 4.3 and 4.4 respectively.

Fig 4.3 Active losses with NTL

In the case where bus 1 is used as the slack bus, the average power loss in the transmission line is around 128.72 Watts (Average of Active Power losses over 24 hours), while the power loss calculated using the average values of power and power factor is 100.23 Watts. The result is that the average of losses calculated using the sum of data from individual times is not equal to the losses calculated using the average values. The maximum active power losses occurred as shown in graph are 670.04 Watts maximum reactive power losses are while 876.9Watts. This has been clearly shown with the help of figures.

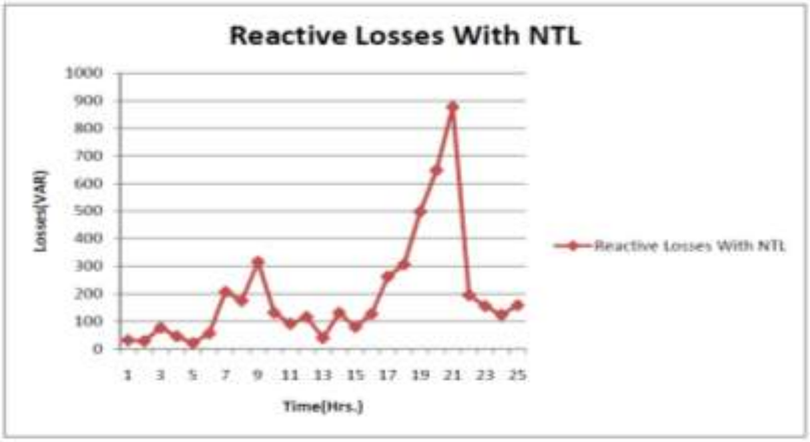

Fig 4.4 Reactive losses with NTL

5. Comparison of Losses

With the addition of NTL to one of the load, the overall system losses will increase. This large increase is only due to small addition i.e. only 3% load. Mainly reactive power losses have higher range than active power losses. The two losses are compared with the help of waveform shown in Figure 5.1 below. The average demand for that same time period is the total energy consumption divided by the length of the time period, in seconds. This information is always available for metered loads, because it is what the utilities' revenues are based on.

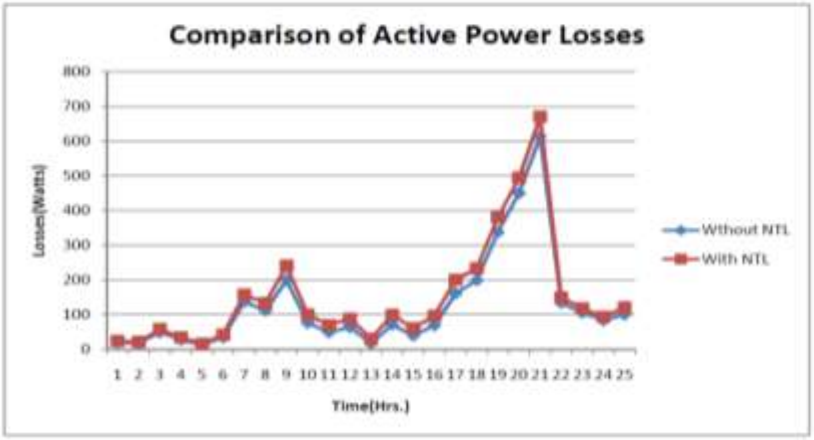

Fig 5.1 Comparison of Active power losses

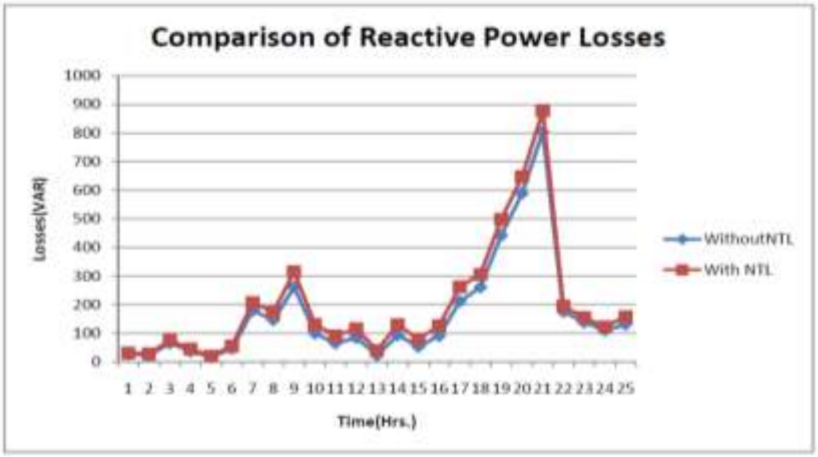

Fig 5.2 Comparison of Reactive power losses

The increase in load demand and the increase in transmission losses are not at the same levels. This is caused by the power factor contribution of the NTL load. Indeed, the losses increased at a greater rate than the loads. The average loss here is computed by averaging the overall loss increase for each hour. The Figure 5.3 shows the net per unit increase in losses at bus 2 where as percentage increase of load and losses due to NTL are also shown in Figures 5.4 & 5.5 respectively.

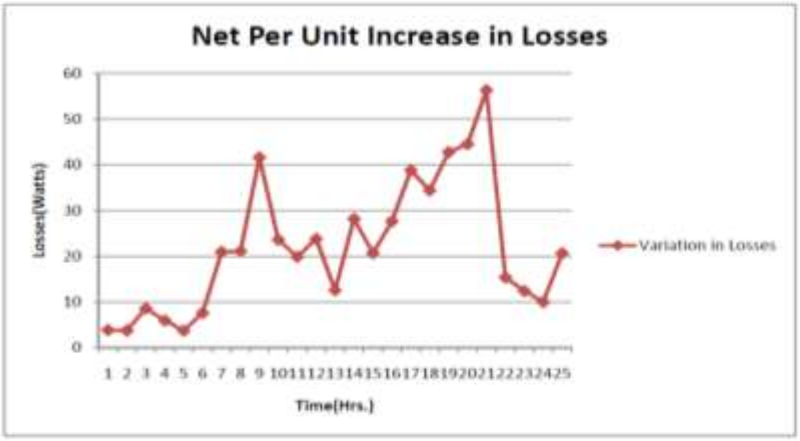

Fig 5.3 Per unit increase in losses

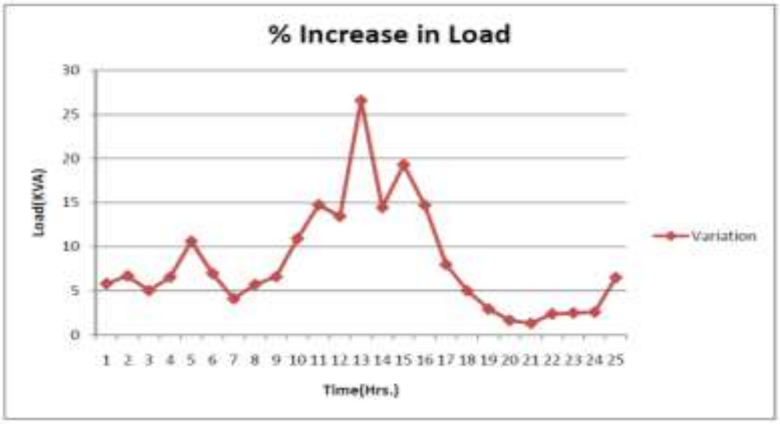

Fig 5.4 Percentage increase in load

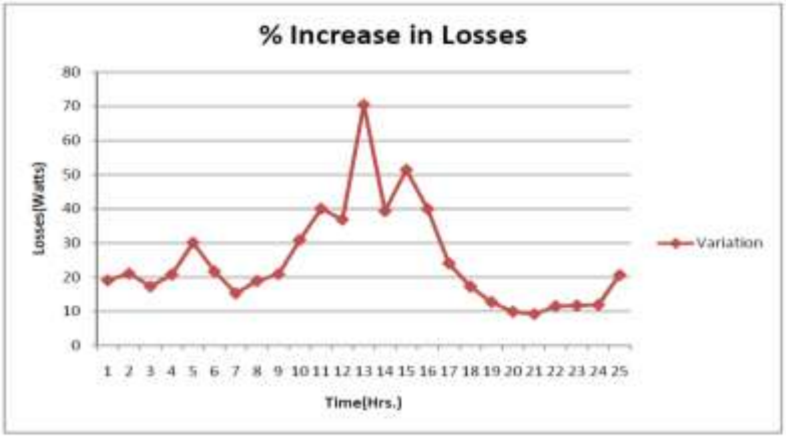

Fig 5.5 Percentage increase in losses

Even though the increase in transmission loss places a greater burden on the transmission equipment, the greater cause for concern would be the NTL load itself. The total power losses in the transmission line are shown in the Figure 5.6 which is sum of NTL active power and losses increase due to NTL. When the lines get overheated, serious consequences can follow, from loss of material strength to the weakening of insulation possibly dangerous if the lines are in a crowded area.

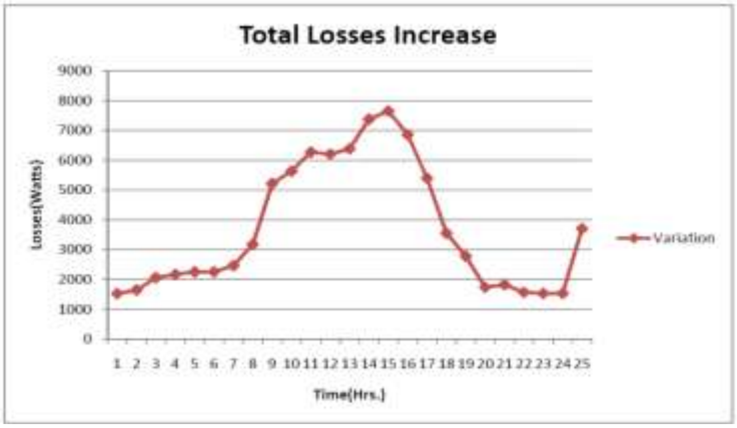

Fig 5.6 Total increase in losses

At this point, it is getting clear that making calculations for expected losses accurately is nearly impossible in practice. The way to obtain a fairly accurate value of average load demand is to utilize the information the utilities use to calculate the electric bills. The calculation requires energy consumption accumulated up to the beginning of the time period and the consumption accumulated at the end of the time period. The accumulated consumption at the end of the period is subtracted by the accumulated consumption at the beginning of the period. The result is the total consumption during the time period in kilowatt-hours, and the portion of the bill for energy consumption is based on this number. The net summary of the simulation results is shown as follows:

Table 5.1 Net Results Summary

Summary of losses	**Calculations on each hour's average basis**	**Calculation on net average basis**
Losses without NTL,(Watts)	128.72	100.23
Losses with NTL,(Watts)	150.73	120.91
Increase in losses (Watts)	22.01	20.682
% Increase in losses (Watts)	17.099	20.635
P.U Load Power at bus 2 without NTL,(Watts)	0.050637	0 .051714
P.U Load Power at bus 2 with NTL,(Watts)	0.054011	0.055081
Increase in load (Watts)	3711.6	3704.7
% Increase in load (Watts)	8.2817	6.5126
Total increased losses(watts) (NTL Real Power plus Increased transmission losses)	3733.6	3725.4

From the above results it has been cleared that reducing non-technical losses will ensure that the cost of electricity to the supplier will be reduced, as less electricity will be used from the power generating company. The cost of the electricity to the customer will therefore also reduce, as the customers will not have to pay for the non-technical losses in the electricity distribution network.

Conclusion

The total system losses are composed of technical & non technical losses. Technical losses are due to physical aspect and Non-technical losses due to unauthorized line tapping or meter by passing. Non technical losses are difficult to measure because of the presence of T & D losses in it and also it is not possible to segregate NTL from them. So the measurement of technical losses using load flow has been developed. These losses when subtracted from the total losses will give the extent of NTL in the system.

In my work a case study has been carried out to determine the extent of losses in that area. The total units supplied and total units billed have been thoroughly measured for one full month. Then their difference is used to determine the extent of losses in that area. I have taken a two bus system with one bus as slack bus and load is on another bus. The load profiles of simple industrial area and residential area has been taken. Then a small percentage of NTL has been added to one of the load and the increased load and losses have been shown with the help of Newton-Raphson load flow method and Matlab. The power factor contributions chosen here are negative because the NTL load is assumed to be inductive. All the simulation results have been shown in the form of bar diagrams clearly. The readings of one full day have been taken.

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