Distribution Simulation Package for Low Voltage Distribution Network

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Abstract
Distribution loads vary in response to temperature, time of the day, day of the week and other factors such as humidity precipitation and season. The effects of daily load patterns of a typical low voltage network (LV network) need to be studied in depth for optimization. This requires a detailed collection of distribution transformer load recordings of all electrical parameters such as voltage, current, power and power factor for all three phases. Load analysis is the detailed systematic study of all load recordings to derive significant conclusions. Hence there arises a need for the development of distribution simulation package (DSP) for LV network load analysis and optimization.

In the design of simulation package, LabVIEW is used as software simulation tool. There are four modules developed in the DSP namely, Load Survey Module, Power measurement Module, Display Module and Unbalance Prediction Module. In the existing system of distribution network, the distribution transformers (DT) are fixed with energy meters in the secondary of the DT and energy meter readings are downloaded with common meter reading instrument (CMRI). The energy meter reading includes voltage current profile (vi – profile) with power factor and serves as input to the DSP. Outputs of DSP are Power and Energy Measurement, Voltage Graph, Load Graph, Power Graph and Prediction of unbalance in the LV distribution Network.
DSP can be termed as effective Management and Monitoring Module (**MMM**) for LV networks. With the DSP, LV networks are studied, analyzed results obtained; Hypotheses derived and significant conclusions are drawn.

Keywords: distribution simulation package, load analysis, lv network, optimization, reconfiguration and unbalance prediction.

1. Introduction
Electrical utility has three functional areas namely generation, transmission and distribution. In the distribution network there are two main distribution network lines namely, primary distribution lines (33kV/22kV/11kV) and secondary distribution lines (415 volts line voltage). Primary distribution lines feed the HT consumers and distribution transformers. The distribution transformers feed the low voltage distribution networks which are the secondary distribution lines. Hence low voltage distribution network (LV network) is the last link connecting the consumers. Each of the primary distribution line leaves the sub-station as a three-phase circuit and supplies a number of distribution transformers. On the secondary side of the distribution transformer, the Secondary distribution lines are connected. The distribution transformers and secondary distribution lines are rated to maintain the voltage received by consumers within a prescribed tolerance over the full range of loading conditions. The Figure 1 shows the distribution system prevalent in India.
The main part of distribution system includes:-

1. Receiving Substation.
2. Sub-transmission lines.
3. Distribution substation located closer to the load centre.
4. Secondary circuits on the LV side of the distribution transformer.
5. Service mains with metering arrangement.

The existing system in the distribution network is manually controlled. The distribution transformers are located at convenient places in the load area. At the distribution transformer, the voltage is stepped down to 415V and power is fed into the secondary distribution systems. The secondary distribution system consists of distributors (Pillar Boxes) which are laid along the road sides. The service connections to consumers are tapped off from the distributors.The main feeders, distributors may consist of overhead lines or cables or both. The distributors are 3- phase, 4 wire circuits, the neutral wire being necessary to supply the single phase loads. There are single phase and three phase services given by the electrical utility depending on the requirement of consumers. The service connections of consumer are known as service mains. A ground connection is normally provided, connected to conductive cases and other safety equipment, to keep current away from equipment and people. For single phase services the phase and neutral conductors from distribution transformer is connected

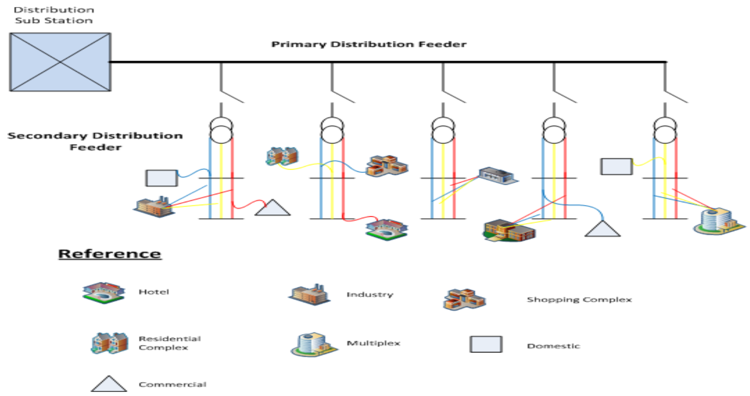


Figure 1 Distribution System

2. Performance of distribution system

The distribution system requires more attention as it is very difficult to standardize due to its complexity. As it involves consumers, power quality becomes paramount consideration in feeding the power supply. With a quality power there is need for uninterrupted supply of power. To avoid shortage of power one important consideration is reduction of transmission and distribution losses. Transmission and distribution losses (t & d losses) in india have been consistently on the higher side between the ranges of 21–25%. Out of these losses, 19% is at the distribution level in which 14% is contributed by technical losses. This is due to inadequate investments for system improvement work. The detailed analysis of distribution transformers with different types of loading patterns have to be studied for solving power quality issues. Such data are not available in scientific way for analysis across the country, India. Therefore, DSP has been developed .Utmost care has been taken to collect the data of LV network from different places like metro, urban and rural populated regions to be analysed using DSP. There are at least data from 100 transformers analyzed before presenting the inferences. Out of 100 transformers, a sample transformer have been presented in this work. The relevant work in the literature for the presented work is summarized below.

Valentina Cecchi and et al (2007) have designed instrumentation and measurement configuration for network configuration and meter placement. The work is in primary distribution network and it is not extended up to secondary distribution network. Aderiano Galindo Leal and et al (2009) describes artificial neural network approach for loss evaluation of distribution transformer. The authors have recorded seven-day load profiles of distribution transformers of Brazilian distribution utility which proves uniformity in stochastic nature of the loads. That is, load profiles of different categories of consumers can be grouped under clusters as residential, commercial and industrial. But it requires daily load profiles of consumers whereas daily load profiles of distribution transformer are only available in developed country’s scenario. Hence development of DSP for developing countries’ is significant contribution for distribution sector.

3. Development of distribution simulation package

In the existing system of distribution network, energy meters are provided for energy accounting. There is no means of sensing unbalance currents, voltage unbalance and power factor correction requirement for continuous 24 hours in three phases of LT Feeder. In other words, load curves, voltage curves, energy curves and power factor curves for individual three phases for full day are not available for monitoring, analyzing and controlling the LV network. To solve this, the modules developed in the DSP are listed below along with their associated function.

- ***Load Survey Module***: Collection of 30 minute readings on the daily load pattern of distribution transformer.
- ***Power measurement Module***: The measurement of power (Real, Reactive and Apparent) and display of voltage –current (vi-profile), power factor and power in the front panel for each phase R, Y and B.
- ***Display Module***: The display of voltage graph showing all three phases, current graph with all three phases, power graph showing all three phases and total power for any selected day for the low voltage distribution network. These graphs are effectively utilized for load analysis and to study the power quality performance of low voltage distribution network.
- ***Unbalance Prediction Module***: Prediction of unbalance in the network for the day selected and display them with LED indicators.

3.1 Design of Simulation Package

In the existing system of distribution network, the distribution transformers are fixed with energy meters in the secondary of the distribution transformer and energy meter readings are downloaded with CMRI. The energy meter reading includes voltage current profile (vi – profile) and power factor. It can be used for power measurement. With additional functionalities developed in this work like plotting of all electrical parameters on graph, prediction of unbalance current, LabVIEW based system can be termed as effective management and monitoring Module (**MMM**) for low voltage distribution networks.

3.1.1 Load Survey Module

The phase voltages, line currents and power factor of all three phases are monitored every half an hour in the meter fixed in the secondary of the distribution transformer. The voltage curve and load curve are obtained from these values. The active, the reactive and the apparent power are computed from these quantities after determining the phase angle. “VI-sub modules” are developed and the parameters listed below are plotted.

- Individual phase voltage.
- Individual phase current.
- Individual phase active power.
- Individual phase reactive power.
- Individual phase apparent power.
- Individual phase power factor.

With the above concepts, the front panel and block diagram are developed for three phase loads by downloading the vi-profile (voltage current profile) from energy meter installed in the distribution transformer and simulating the setup using practical values. From the actual values obtained load unbalance is predicted.

3.1.2 Power Measurement Module Design

The energy meter reading which includes vi-profile with power factor serves as one of the inputs to LabVIEW system. It consists of 30 minute readings and hence 48 samples per day. The other input for power calculation and display of voltage graph, current graph, power graph and energy graph is the ‘day’ input. For particular transformer and particular day of the month selected, all graphs of electrical parameters and power measurement has been designed in the block diagram of LabVIEW and displayed in the Front panel. Figure 2 shows the subVI for displaying the vi-profile on a particular date. The subVI for the measurement of power is shown in Figure 3. The block diagram for design of measurement of power is displayed in Figure 4.

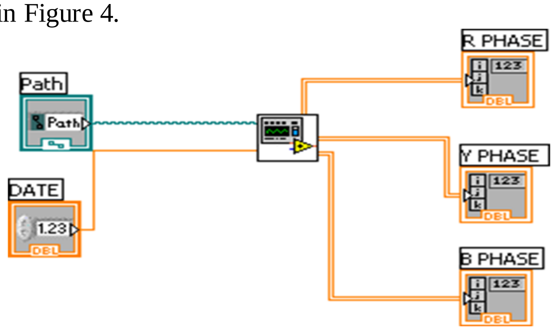


Figure 2 SubVI for vi-Profile

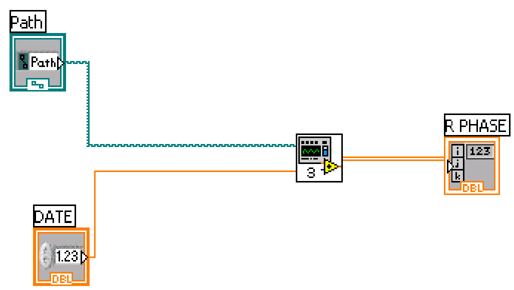


Figure 3 SubVI for Measurement of Power

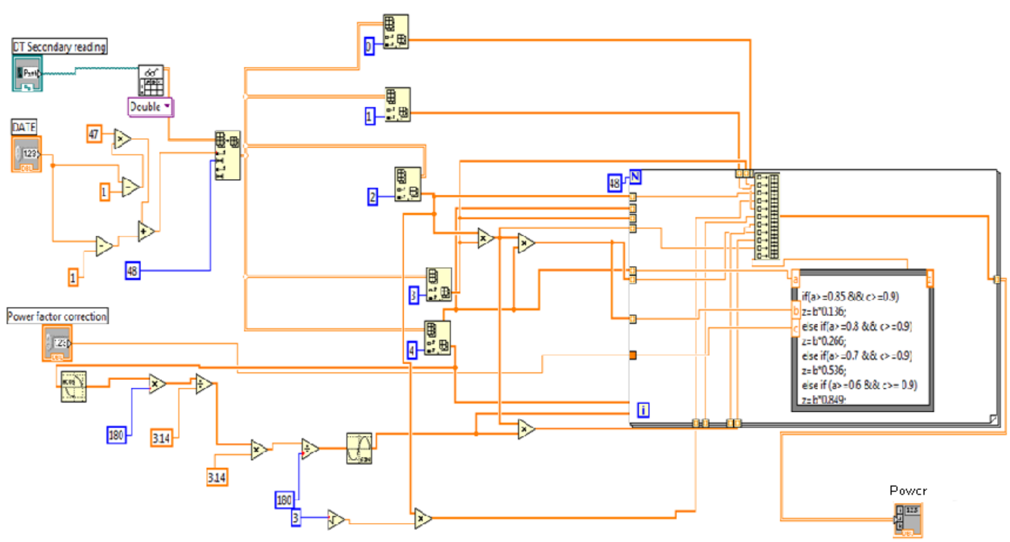
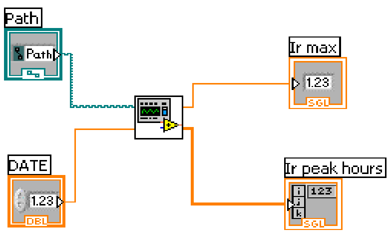


Figure 4 Block Diagram for Measurement of Power

3.1.3 Unbalance Prediction Module

Load analysis of transformer has to be done for full month to check for the consistency and stochastic nature of the loads. To balance the current in the secondary distribution network, only the peak load period is considered since the loads are predominant at peak load. The unbalance effect is more during peak loads. By attempting load balance during peak hours gives better performance throughout the day. SubVI for finding the maximum current in a particular day and particular phase is shown in Figure 5 and subVI for prediction of current unbalance is shown in Figure 6.



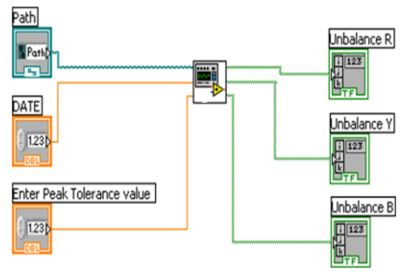


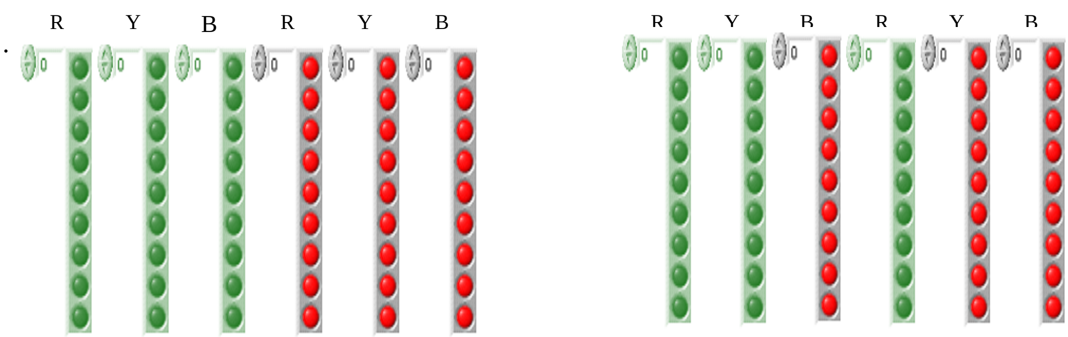
Figure 5 SubVI for Maximum Current **Figure 6 SubVI for Prediction of Current Unbalance**

The subVI displays the maximum current in a particular phase and it also displays current consumption in the peak load hours. In similar way, the LabVIEW is designed for all three phases.

The maximum current consumption in each phase is I_{Rmax}, I_{Ymax}, and I_{Bmax}. The optimum current (I_{opt}) is given by equation 1

$$I_{opt}= (I_{Rmax} +I_{Ymax} + I_{Bmax})/3 \qquad (1)$$

The difference between I_{opt} and I_{Rmax} is then determined. Similarly the difference between I_{opt} and I_{Ymax} , I_{opt} and I_{Bmax} is computed. If the difference is positive then that phase is considered as overloaded and if the difference is negative then that phase is considered to be under loaded. If the difference is within the tolerance value, then that load is perfectly balanced. If there is unbalance, then it is displayed by the LED indicators as in Figure 7. Unbalance in particular phase is indicated by "RED" indication and balanced condition of particular phase is indicated by "GREEN" indication



Balanced Condition Unbalanced condition Balanced Condition in two phases Unbalanced Condition in two phases

Figure 7 Display of Balanced/Unbalanced condition in LV Network

For the peak period, four hours is selected. There are 9 sets of reading for every half-an-hour. For example, if the peak period is 18 hrs to 22 hrs there will be nine set of half–an-hour reading starting with 18hrs reading and ending with 22hrs reading. LED display indicates the time of unbalance during peak hours and extent of unbalance studied from load graph display.

3.2 Load analysis

Load analysis of distribution transformers with different loading patterns deduces significant inferences for the work presented in this paper. For performing load analysis, distribution simulation package developed as discussed in Section 3.1 is effectively utilized. One number sample transformer has been presented in this paper as case study. Typical loads on low voltage networks are stochastic by nature. However it has to be ensured that there is similarity in stochastic nature throughout the day. For arriving at practical and effective conclusion for formulating this pragmatic methodology and to solve the power quality issues, the study has been undertaken using DSP.

Input to the DSP

- Low voltage distribution album of distribution transformer.
- Meter readings of distribution transformer (30minute readings).

Output from the DSP

- Power measurement
- Voltage graph
- Load (Current Graph)
- Power graph and Total power

3.2.1 Load Analysis of Sample Distribution Transformer

The schematic diagram with low voltage distribution album is shown in Figure 8. Energy Measurement for one day is shown in Figure 9 and load graphs for 2 different days taken at random are shown in Figure 10 and Figure 11.

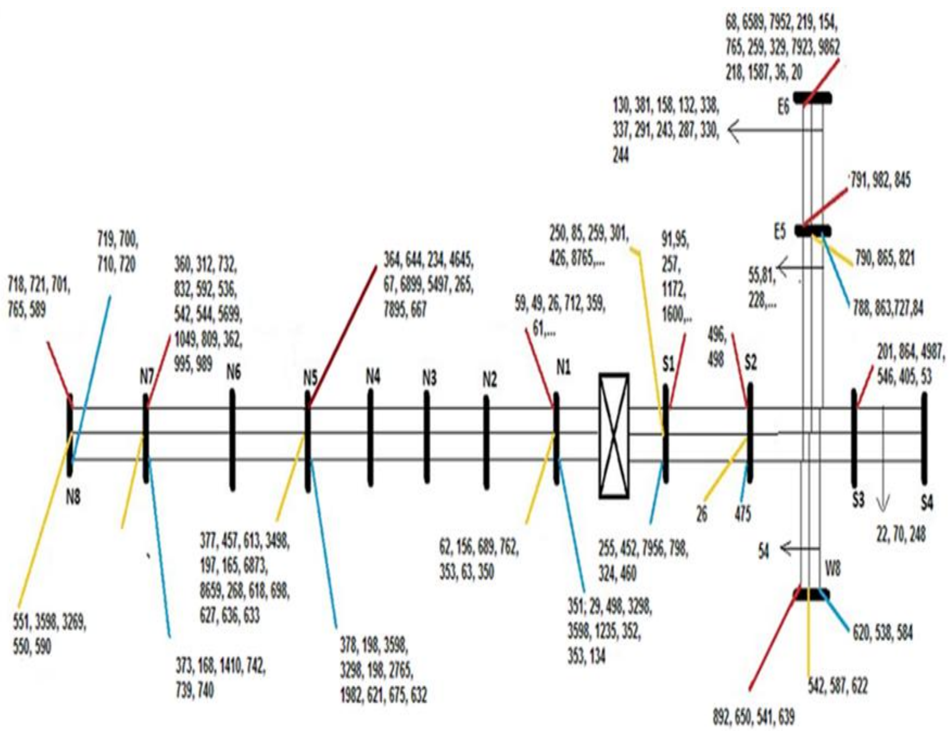
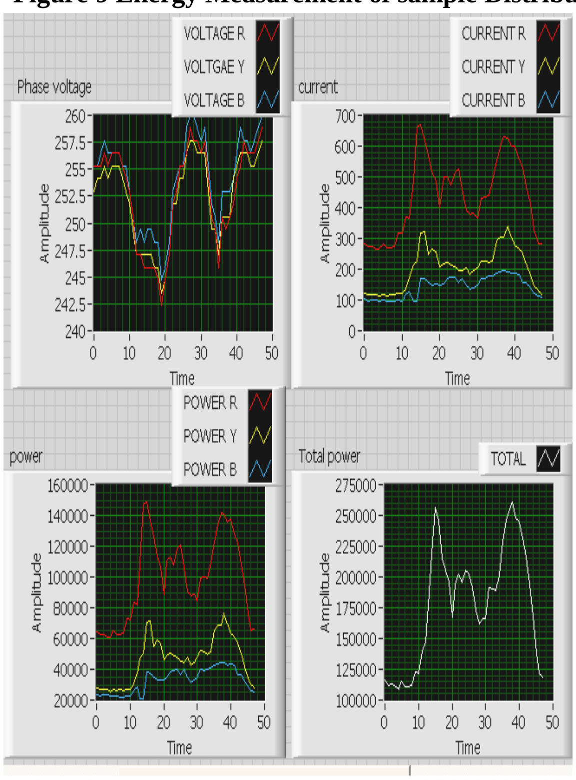


Figure 8 LT Album of Sample Distribution Transformer

Measurement of power and energy in low voltage distribution network

Date	Time	Voltage			Current			Active Power			Power Factor			Total Power	kWh
		R	Y	B	R	Y	B	R	Y	B	R	Y	B		
5/8/2009	0:00:00	255.29	254.12	256.47	275.4412	182.27	109.2227	63.29	41.69	25.21	0.9	0.9	0.9	130.18	65.09
5/8/2009	0:30:00	256.47	254.12	256.47	275.1129	175.8329	110.9525	63.5	40.21	25.61	0.9	0.9	0.9	129.33	64.66
5/8/2009	1:00:00	256.47	254.12	257.65	271.1734	171.0899	106.5045	62.59	39.13	24.7	0.9	0.9	0.9	126.42	63.21
5/8/2009	1:30:00	257.65	255.29	258.82	271.1734	176.8493	106.5045	62.88	40.63	24.81	0.9	0.9	0.9	128.32	64.16
5/8/2009	2:00:00	258.82	255.29	258.82	273.4715	171.7674	106.0103	63.7	39.47	24.69	0.9	0.9	0.9	127.86	63.93
5/8/2009	2:30:00	258.82	256.47	258.82	268.547	173.4614	98.8441	62.55	40.04	23.02	0.9	0.9	0.9	125.62	62.81
5/8/2009	3:00:00	257.65	255.29	258.82	263.2942	182.27	101.8094	61.05	41.88	23.72	0.9	0.9	0.9	126.65	63.32
5/8/2009	3:30:00	257.65	255.29	258.82	281.3506	190.7398	104.5276	65.24	43.82	24.35	0.9	0.9	0.9	133.41	66.71
5/8/2009	4:00:00	256.47	254.12	257.65	287.9165	182.27	107.7401	66.46	41.69	24.98	0.9	0.9	0.9	133.13	66.56
5/8/2009	4:30:00	256.47	254.12	256.47	293.1693	208.6957	125.7791	67.67	47.73	29.03	0.9	0.9	0.9	144.43	72.22
5/8/2009	5:00:00	255.29	254.12	254.12	335.5196	226.6517	115.6476	77.09	51.84	26.45	0.9	0.9	0.9	155.38	77.69
5/8/2009	5:30:00	252.94	250.59	251.76	401.8356	323.5462	118.3658	91.48	72.97	26.82	0.9	0.9	0.9	191.27	95.63
5/8/2009	6:00:00	249.41	248.24	249.41	488.8343	309.3169	102.5508	109.73	69.11	23.02	0.9	0.9	0.9	201.85	100.93
5/8/2009	6:30:00	242.35	243.53	243.53	540.377	375.0425	111.6938	117.86	82.2	24.48	0.9	0.9	0.9	224.55	112.27
5/8/2009	7:00:00	236.47	237.65	237.65	634.9265	421.457	154.9381	135.13	90.14	33.14	0.9	0.9	0.9	258.41	129.2
5/8/2009	7:30:00	241.18	243.53	243.53	640.5076	403.1622	141.8413	139.03	88.36	31.09	0.9	0.9	0.9	258.48	129.24
5/8/2009	8:00:00	241.18	242.35	243.53	528.5583	343.8737	167.0465	114.73	75	36.61	0.9	0.9	0.9	226.35	113.17
5/8/2009	8:30:00	241.18	242.35	244.71	540.7053	458.7241	206.0899	117.37	100.05	45.39	0.9	0.9	0.9	262.81	131.41
5/8/2009	9:00:00	241.18	241.18	243.53	509.517	501.7506	207.8197	110.6	108.91	45.55	0.9	0.9	0.9	265.06	132.53
5/8/2009	9:30:00	245.88	245.88	248.24	406.1035	425.1837	190.2749	89.87	94.09	42.51	0.9	0.9	0.9	226.47	113.23
5/8/2009	10:00:00	249.41	249.41	251.76	464.5404	382.4959	154.1968	104.27	85.86	34.94	0.9	0.9	0.9	225.07	112.54
5/8/2009	10:30:00	249.41	249.41	251.76	428.4277	374.0261	152.7141	96.17	83.96	34.6	0.9	0.9	0.9	214.73	107.36
5/8/2009	11:00:00	250.59	249.41	252.94	383.1227	359.7969	149.2546	86.41	80.76	33.98	0.9	0.9	0.9	201.15	100.57
5/8/2009	11:30:00	250.59	250.59	252.94	427.4428	379.4468	143.3239	96.4	85.58	32.63	0.9	0.9	0.9	214.61	107.3
5/8/2009	12:00:00	252.94	251.76	254.12	357.1872	328.9668	145.795	81.31	74.54	33.34	0.9	0.9	0.9	189.2	94.6
5/8/2009	12:30:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/8/2009	13:00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/8/2009	13:30:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/8/2009	14:19:00	256.47	256.47	257.65	428.0994	344.2125	160.3746	98.82	79.45	37.19	0.9	0.9	0.9	215.46	107.73
5/8/2009	14:30:00	256.47	256.47	258.82	384.4359	326.2565	151.7257	88.74	75.31	35.34	0.9	0.9	0.9	199.39	99.69
5/8/2009	15:00:00	255.29	255.29	257.65	369.3342	280.5196	117.3774	84.86	64.45	27.22	0.9	0.9	0.9	176.53	88.26
5/8/2009	15:30:00	256.47	255.29	257.65	236.3739	202.5975	73.39174	54.56	46.55	17.02	0.9	0.9	0.9	118.13	59.06
5/8/2009	16:00:00	255.29	255.29	257.65	256.7283	229.7008	76.10996	58.99	52.78	17.65	0.9	0.9	0.9	129.41	64.71
5/8/2009	16:30:00	255.29	255.29	257.65	301.705	282.8911	75.61574	69.32	65	17.53	0.9	0.9	0.9	151.85	75.93
5/8/2009	17:03:00	255.29	255.29	257.65	323.3726	227.6681	95.63167	74.3	52.31	22.18	0.9	0.9	0.9	148.78	74.39
5/8/2009	17:30:00	251.76	251.76	254.12	427.7711	333.7099	139.6173	96.93	75.61	31.93	0.9	0.9	0.9	204.47	102.24
5/8/2009	18:00:00	248.24	249.41	251.76	514.4415	449.2379	220.4223	114.93	100.84	49.94	0.9	0.9	0.9	265.72	132.86
5/8/2009	18:30:00	248.24	249.41	251.76	559.4182	470.5818	234.7547	124.98	105.63	53.19	0.9	0.9	0.9	283.81	141.9
5/8/2009	19:00:00	249.41	250.59	251.76	615.2287	495.9912	236.4845	138.1	111.86	53.58	0.9	0.9	0.9	303.54	151.77
5/8/2009	19:30:00	251.76	252.94	255.29	639.1944	504.461	272.3155	144.83	114.84	62.57	0.9	0.9	0.9	322.24	161.12
5/8/2009	20:00:00	254.12	255.29	256.47	615.557	479.3904	233.025	140.78	110.15	53.79	0.9	0.9	0.9	304.72	152.36
5/8/2009	20:30:00	254.12	255.29	257.65	584.6971	442.8009	210.5379	133.72	101.74	48.82	0.9	0.9	0.9	284.28	142.14
5/8/2009	21:00:00	251.76	252.94	254.12	541.0336	401.4683	202.3833	122.59	91.39	46.29	0.9	0.9	0.9	260.27	130.13
5/8/2009	21:30:00	255.29	255.29	257.65	465.8535	352.0047	169.7647	107.03	80.88	39.37	0.9	0.9	0.9	227.28	113.64
5/8/2009	22:00:00	254.12	252.94	255.29	406.4318	313.0436	149.7488	92.95	71.26	34.41	0.9	0.9	0.9	198.62	99.31
5/8/2009	22:30:00	255.29	254.12	256.47	323.3726	281.8748	133.6866	74.3	64.47	30.86	0.9	0.9	0.9	169.62	84.81
5/8/2009	23:00:00	255.29	254.12	256.47	294.1542	209.0345	116.8831	67.59	47.81	26.98	0.9	0.9	0.9	142.37	71.19
5/8/2009	23:30:00	257.65	255.29	257.65	275.4412	197.5156	112.6823	63.87	45.38	26.13	0.9	0.9	0.9	135.38	67.69
Distribution transformer cumulative kilo watt hour in kWh															4431.29

Figure 9 Energy Measurement of sample Distribution Transformer



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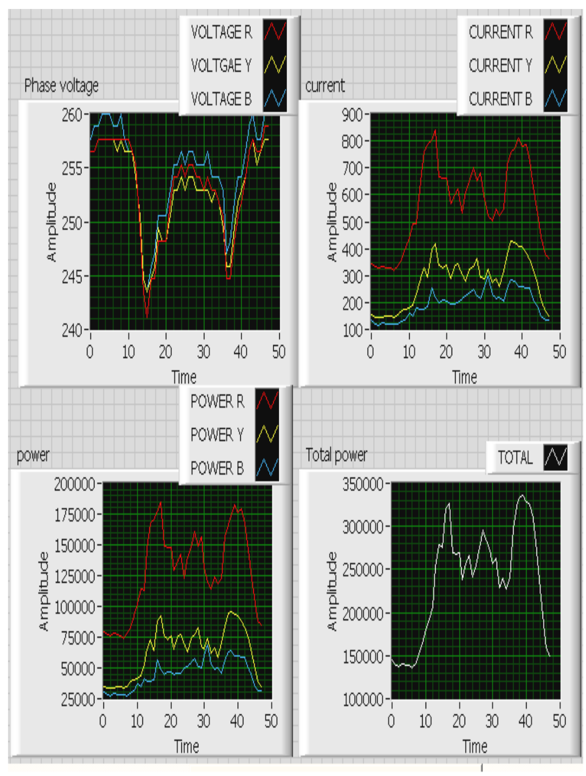

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Figure 10 Load Graphs

Figure 11 Load Graphs

3.3 Results and Discussions

The detailed analysis of distribution transformers with different types of loading patterns leads to very interesting findings as summarized below.

- Though the load utilization of individual consumers is a variable factor, there is uniformity found in stochastic nature.
- The per-capita consumption of electricity is high in urban compared to rural areas.
- The peaks and valleys in load graphs tend to follow similarity though not identical in all types of distribution network.
- The high peak occurs in approximately same band of one hour every day, the major variation may be two hours which is also very rare.
- The peak load of the transformer occurs when majority of the consumers connected to distribution network utilizes most of the loads. It occurs in the same time band of peak load of the distribution transformer due to prevailing culture and habit of the people.
- The percentage of unbalance between phases is observed to be proportionate and hence value of unbalance will be maximum during peak loads.

3.4. Conclusion

All the inferences made out of low voltage distribution network load analysis prove that optimization of low voltage distribution network can be achieved by proper planning and successful reconfiguration of consumers to avoid unbalance of loads in distribution LV network. This distribution package serves as a backbone for the load analysis. With this method of load analysis and load reconfiguration there is a possibility of energy saving in terms of millions of rupees to the nation.

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