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A Smart Approach for Demand Side Load Management

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***Abstract* — As India is moving towards its power system reliability and has become much of concern and a part of study for making it more and more efficient, its power sector needs to follow some economical practices to achieve reasonable voltage regulation for making the system more adequate. This research paper presents A Novel Approach for Demand Side Load Management by re-allocation of load on a distribution transformer from peak hours to off-load-peak hours in order to improvising its voltage regulation. As it is yet another approach of achieving voltage regulation for 11kV distribution feeder by proper load management. The case study is carried on an 11kV feeder and the improvement in its voltage regulation is tabulated by appropriate load management at distribution side. The results are obtained and cross verified by writing a code/program for voltage regulation computations by using MATLAB/code.**

Keywords — Demand Side Load Management; Distribution Transformer; Load Centre; Voltage Regulation; Power System Reliability.

I. INTRODUCTION

The consumers are subjected to inconvenience with frequent power cuts, fluctuating voltages and frequencies which results in system losses which are high throughout India’s Transmission and Distribution networks. Thus India’s power sector needs to make the system more adequate and more efficient form reliability point of view. Therefore distribution sector requires an economical system which can provide electrical energy at a suitable price with minimum voltage drop and with reduced voltage regulation.

A few suitable economical practices are to be followed in order to achieve reasonable regulation which can improve the quality and economy of electricity distribution process which is growing in size year by year in India.

In the case of overhead networks, the limiting factor to load carrying capacity is generally the voltage reduction. The performance of a feeder supplying load through number of transformers by maintaining the specified voltage level till the tail end of the feeder which contribute in determining the figure of merit of a distribution system. As electrical energy occupies the top grade in energy hierarchy and steps are been taken to improve it by various projects carried out in India such as APDRP works (Accelerated Power Development and Reform Program) in urban areas and RLMS (Rural Load Management System) for development of rural areas during the year 2003 to 2010. These projects find innumerable uses in domestic, agriculture, commercial and industrial power sector.

The electrical power network can be subdivided into Generation, Transmission and Distribution systems, where substations are installed in a transmission and distribution system. These involve the connection of different sections of networks in the form of feeders which usually transfer electric power from one voltage level to another. Thus substation plays a vital role in integrating the generation, transmission and distribution parts of an electrical network and hence is an important part of study.

II. DISTRIBUTION SYSTEM AND NETWORK

A. *Disrubution System*

Distribution system serves as the link from the distribution substation to the consumers. This system provides the safe and reliable transfer of electrical energy to various consumers through the service territory by means of service lines.

Distribution systems are designed so that all consumers along the feeder will receive voltage within a specified range during the peak as well as in off-peak load conditions. The difference between the voltage set at substation and the voltage received by the consumers farthest from the substation is directly related to the load conditions. As distribution voltages vary depending on consumers need, equipment and its availability.

B. *Distribution Network*

Distribution networks are mainly of two types, Radial or Interconnected. A radial network leaves the station and passes through the network area with no normal connection to any other supply. This is typical a long rural lines with isolated load areas. An interconnected network is generally found in urban areas and will have multiple connections to other points of supply. These points of connection are normally open but allow various configurations by the operating utility by closing and opening of isolators or gang operating switches. The benefit of an interconnected model is that in the event of a fault or under maintenance and service condition a small area of network can be isolated and troubleshooting of the line can be done by taking precautions and safety measures. Under these conditions a grounding is been done by means of an earth rod connected at the supply side entrance.

C. Disrubution Lines

Role of Distribution Lines is to deliver power from substations to load or consumers, thus for distribution of power, 3-phase 4-wire or 3-phase 5-wire (1-wire used as street light in city areas) AC system is usually adopted. Similarly the distribution system is either Primary or Secondary distribution. The voltage level for primary distribution is 33kV or 11kV and the voltage level for secondary distribution is 415V for large industrial load and 240V for domestic load. Feeders play a vital role in connecting substation to the areas of consumers with the help of distribution transformers. Generally from feeders, no tapings are taken/provided to consumers. So the current loading of a feeder remains the same along its length. It is based on its current carrying capacity and the voltage also remains the same as 11kV or 33kV.

III. PROBLEM FORMULATION

Nowadays two factors are mainly considered while evaluating the performance and study of a distribution system in general, a feeder in particular and the voltage level at the tail end with the losses occurring in the system.

A feeder with the number of distribution transformers connected in it to supply power to different types of load. These distribution transformers are with different capacities. In practice these distribution transformers are not strictly loaded as per their capacity provided due to various priorities. Hence there is an avenue to take a case study in which the performance parameters of the feeder is evaluated with the existing load pattern and connected load. Further, the load will be re-allocated on the distribution transformer by studying for its loading and its peak and off-peak hours as per the load condition connected to the feeder and the evaluation will be repeated. The results are then compared to draw an inference and hence a voltage profile is maintained.

Thus the case study is formulated with the following objectives:

- To locate the state of the art practice in evaluating the performance of feeder.
- Collect the field data (capacity of distribution transformers, load pattern on distribution transformers etc) pertaining to a feeder with ten transformers connected to it.
- Evaluate the performance for the existing conditions.
- Implement load management or re-allocate the loads on the distribution transformer according to its load condition and recomputed the performance.

IV. METHODOLOGY

The proposed method calculates the voltage drop for the existing load condition to determine the feeder current and the tail end voltage of the feeder. Further, the calculation is done with the application of the load management for several permutation and combination of load pattern and the change in voltage drop is observed.

Case 1: Evaluation of the performance of the feeder and distribution transformers with the existing load conditions.

An 11kV feeder line with number of distribution transformers connected to the feeder line is shown in figure 1.

Each distribution transformer is of different capacity and is connected to different areas of supply power such as residential, commercial and industrial loads.

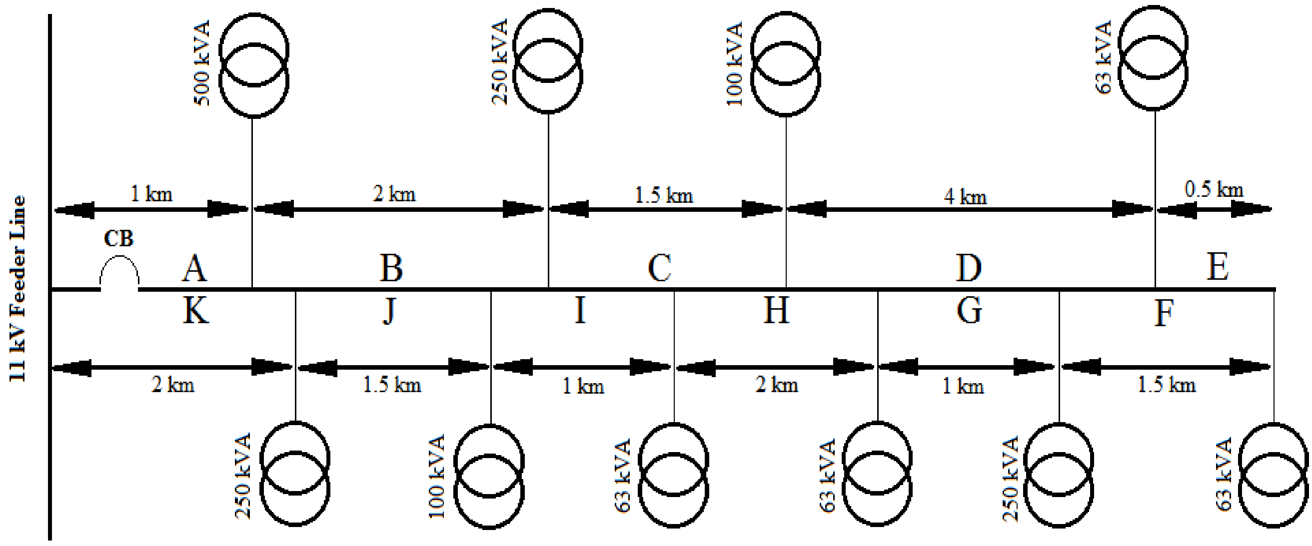
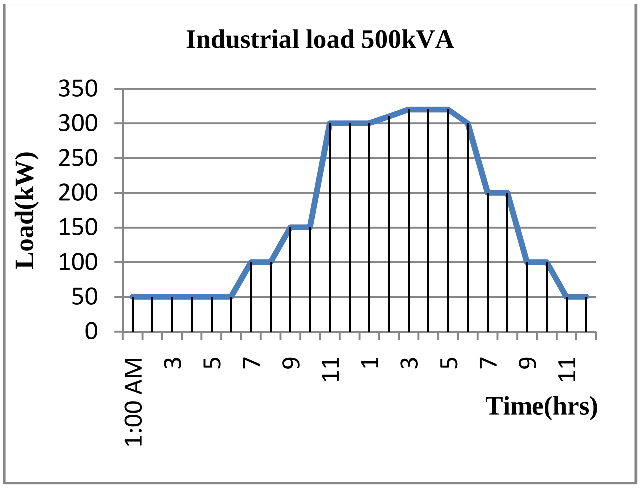
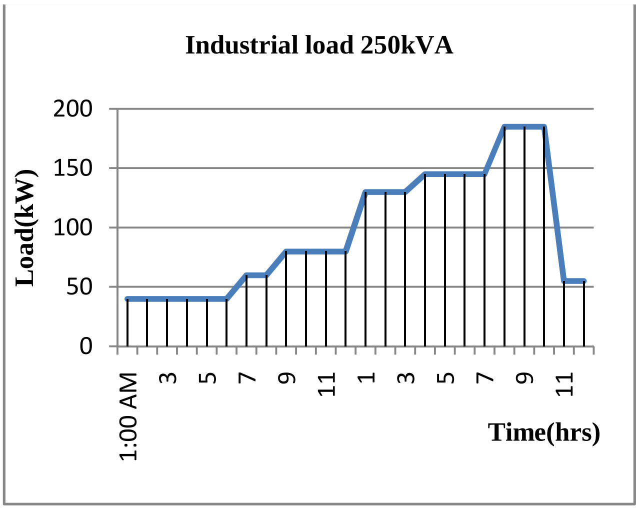
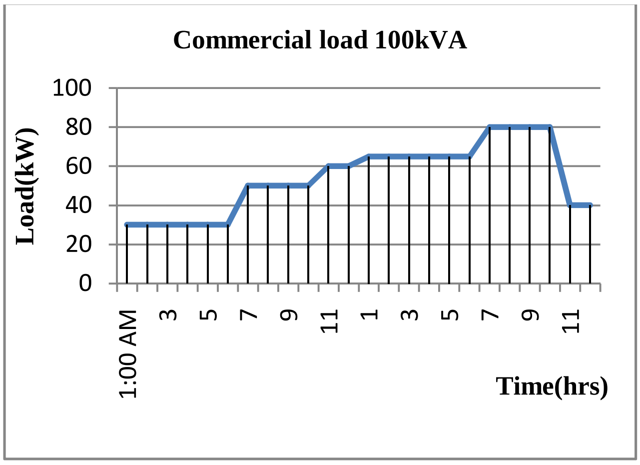


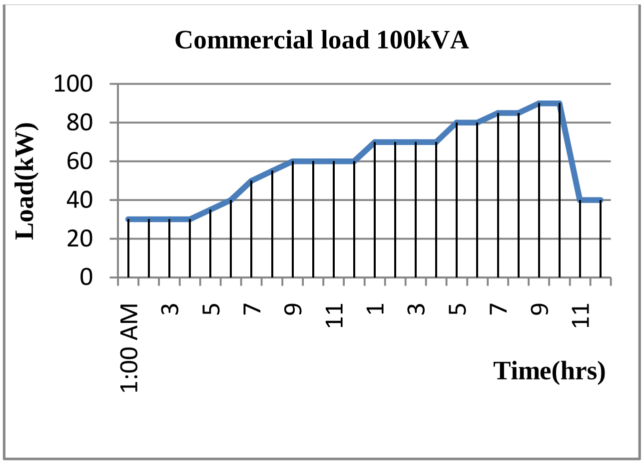
Fig. 1. Shows a 11kV feeder line

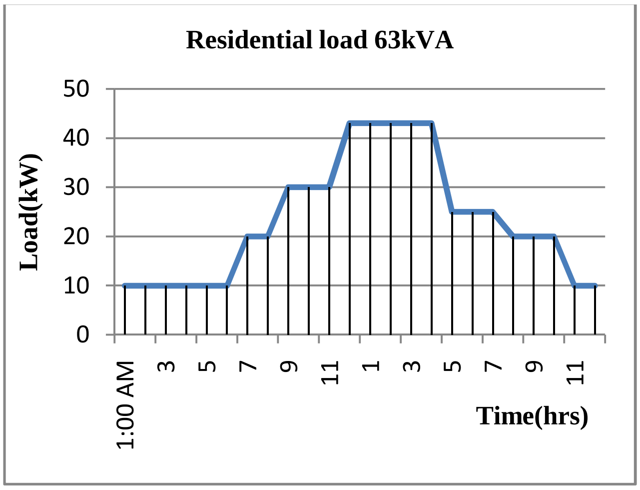
The below figure 2, shows the load curves for different areas for which the tail end voltage is calculated.

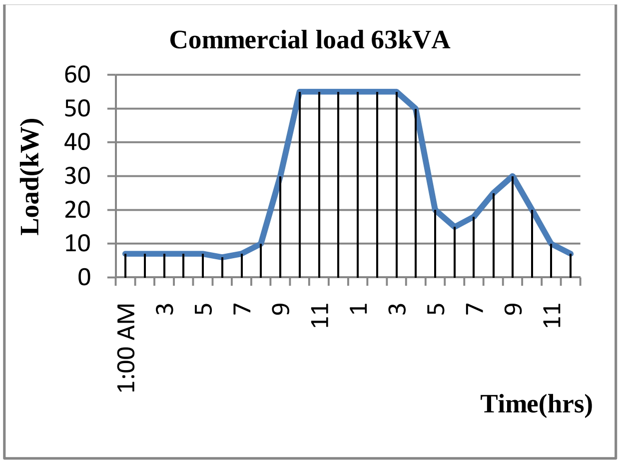


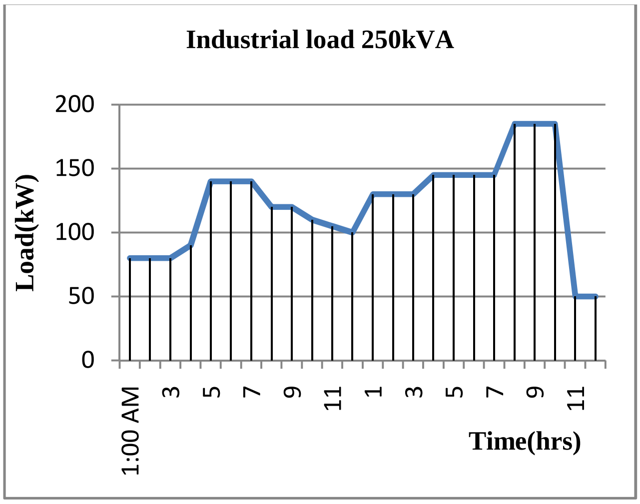


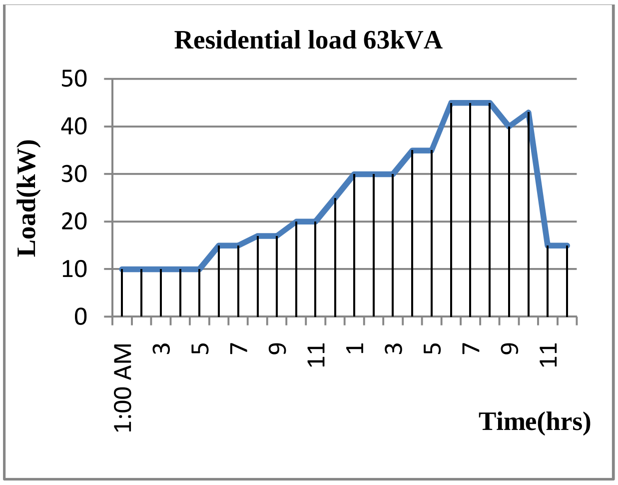

Commercial load 100kVA
Load(kW)
Time(hrs)


Commercial load 100kVA
Load(kW)
Time(hrs)


Residential load 63kVA
Load(kW)
Time(hrs)


Commercial load 63kVA
Load(kW)
Time(hrs)


Industrial load 250kVA
Load(kW)
Time(hrs)


Residential load 63kVA
Load(kW)
Time(hrs)

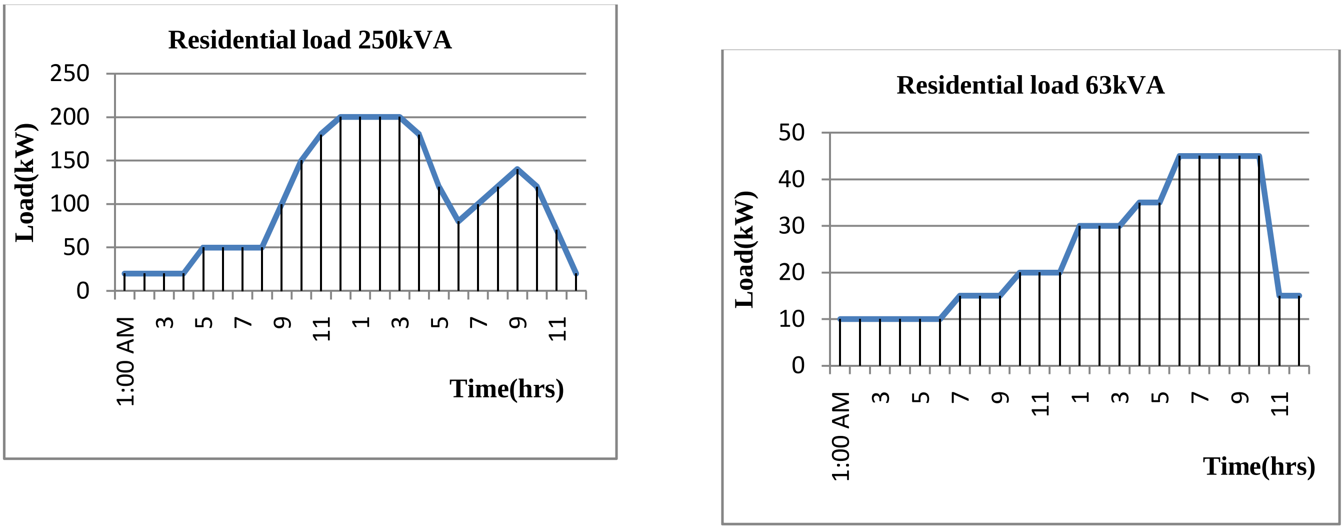


Fig. 2. Load curves of different sectors

The summative load curve reflecting on the feeder is as shown below in figure 3.

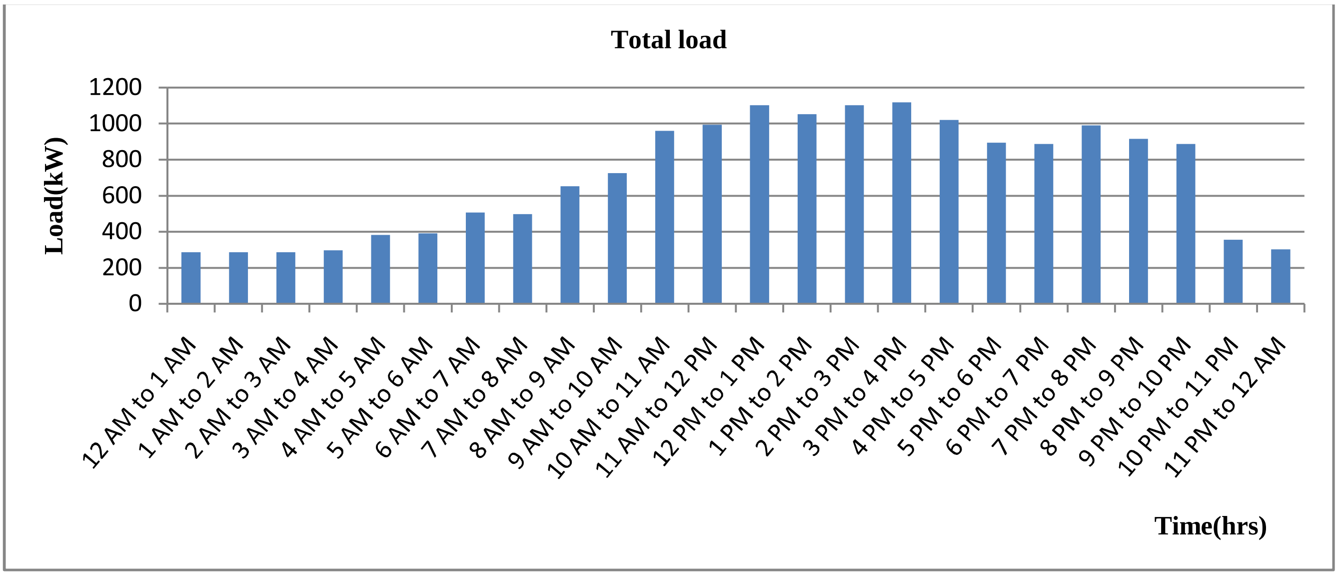


Fig. 3. Total load on the system

Voltage regulation calculations:

Units distributed/day

$$= (287 \times 1) + (287 \times 1) + (287 \times 1) + (297 \times 1) + (382 \times 1) + (391 \times 1) + (507 \times 1) + (497 \times 1) + (652 \times 1) + (725 \times 1) + (910 \times 1) + (943 \times 1) + (1053 \times 1) + (1063 \times 1) + (1073 \times 1) + (1088 \times 1) + (990 \times 1) + (945 \times 1) + (888 \times 1) + (990 \times 1) + (915 \times 1) + (888 \times 1) + (355 \times 1) + (302 \times 1)$$

$$Units\ distributed/day = 16715\ kWh$$

$$Load\ factor = \frac{Units\ distributed\ per\ day}{maximum\ demand \times 24\ h}$$

$$\therefore Load\ factor = \frac{16715}{1088 \times 24} = 0.6401 \times 100$$

$$\therefore Load\ factor = 64.01\ \%$$

$$Diversity\ factor = \frac{Sum\ of\ individual\ maximum\ demand}{max\ demand\ on\ the\ system}$$

$$= \frac{\mathbf{320} + 185 + 80 + 43 + 185 + 90 + 55 + 45 + 200 + 45}{1088}$$

$$= \frac{1248}{1088} = 1.147$$

$$\therefore Diversity\ factor = 1.14$$

Note: When data of maximum demand on the primary feeder (11kV) is not available, then the sum of kVA ratings of all distribution transformers installed on the feeder and the diversity factor is used to find out the maximum demand of the feeder.

$\therefore The\ total\ distribution\ transformer\ capacity\ connected\ to\ feeder$

$= (500 \times 1) + (250 \times 3) + (100 \times 2) + (63 \times 4)$

$\therefore Total\ kVA = 1702\ kVA$

$$\therefore The\ maximum\ demand = \frac{Total\ kVA\ capacity}{Diversity\ factor}$$

$$\therefore The\ maximum\ demand = \frac{1702}{1.14} = 1492.98\ kVA$$

$$\therefore The\ maximum\ feeder\ current = \frac{P}{\sqrt{3} \times V}$$

$$= \frac{1492.98 \times 10^3}{\sqrt{3} \times 11 \times 10^3} = 78.36\ A$$

For 11 kV line, considering ACSR (Aluminium Conductor Steel Reinforced) conductor of cross sectional area $30mm^2$ the respective resistance is R= $\frac{\rho l}{A}$

where,

$\rho = resistivity\ of\ conductor\ for\ Al = 2.83 \times 10^{-8}\Omega/km$

$l = Length\ of\ line = 1\ km$

$A = Cross\ sectional\ area\ mm^2$

$\therefore R = 0.9433\ \Omega/km$

The Percentage Voltage drop can be calculated by,

$$\%\ Voltage\ drop = \sqrt{3} \times I \times \frac{(R\cos\phi + X\sin\phi) \times L \times 100}{V \times N \times 1000}$$

$I = Full\ load\ current$

$L = Cable\ length$

$V = Line\ voltage$

$N = number\ of\ runs\ of\ conductor$

TABLE I. OBSERVATION

SI. No.	CALCUATION			
	DESCRIPTION	***FEEDER CURRENT (Amps)***	***WITHOUT REACTANCE***	***WITH REACTANCE***
1.	**% Voltage drop**	78.36	17.80	18.74

Case 2: Evaluation of the performance of the feeder and transformers with re-allocation of load (with load management). Since each area has a distinct demand profile.

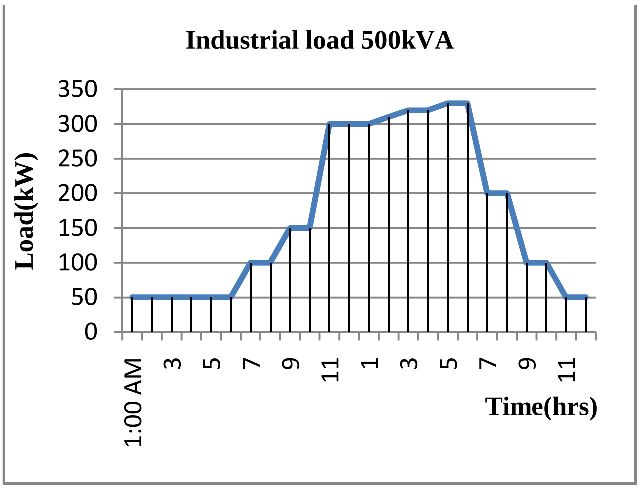


Fig. 4. Re-allocation of load

$$Diversity\ factor = \frac{Sum\ of\ individual\ maximum\ demand}{max\ demand\ on\ the\ system}$$

$$= \frac{\mathbf{330} + 185 + 80 + 43 + 185 + 90 + 55 + 45 + 200 + 45}{1093}$$

$$= \frac{1258}{1088} = 1.150$$

$\therefore Diversity\ factor = 1.15$

The Percentage Voltage drop can be calculated by,

$$\%\ Voltage\ drop = \sqrt{3} \times I \times \frac{(R\cos\phi + X\sin\phi) \times L \times 100}{V \times N \times 1000}$$

TABLE II. OBSERVATION

SI. No.	CALCUATION			
	DESCRIPTION	***FEEDER CURRENT (Amps)***	***WITHOUT REACTANCE***	***WITH REACTANCE***
1.	**% Voltage drop**	77.67	17.65	18.57

Coding/Program:

```
clc; %Clear
SMD = input('Enter the sum of individual maximum demand = ');
MD = input('Enter the maximum demand on the system = ');
DF = SMD/MD; %Diversity factor calculation
disp('The diversity factor is = ');
```

```
disp(DF)
%Maximum demand calculation
TKVA=1702; % Total kVA capacity of connected transformer
MDS = TKVA/DF; % Maximum demand on the system
K = sprintf('%f',MDS);
disp('The maximum demand is = ');
disp(K)
%maximum feeder calculations
V=11; %system voltage
Z=1.732*V;
I= MDS/Z;
disp('The maximum feeder current is = ');
disp(I)
L=18;phi1=0.85; %system data
R=0.9433; %resistance and of the line
%initial value
N=1;phi2=0.526;
%computation of voltage drop
x=phi1;
y=phi2;
m=R*x;
C=m;
A=I*C*L*1.732;
B=V*N*1000;
E=A/B;
VD=E*100;
disp('The percentage voltage drop without reactance is = ');
disp(VD)
%computation of voltage drop with reactance
X=0.08;%reactance of the line
x=phi1;
y=phi2;
m=R*x;
n=X*y;
C=m+n;
A=I*C*L*1.732;
B=V*N*1000;
E=A/B;
VD=E*100;
disp('The percentage voltage drop with reactance is = ');
disp(VD)
```

Output of the program:

Enter the sum of individual maximum demand = 1258

Enter the maximum demand on the system = 1088

The diversity factor is =

1.1563

The maximum demand is =

1472.000000

The maximum feeder current is =

77.2622

The percentage voltage drop without reactance is =

17.5575

The percentage voltage drop with reactance is =

18.4790

V. RESULTS

Hence, case1 and case2 are verified by using MATLAB/code running the program and the results are been tabulated as shown in table III.

TABLE III. RESULTS TABULATED FROM MATLAB/CODE

SI. No.	% VOLTAGE DROP			
	DESCRIPTION	***FEEDER CURRENT (Amps)***	***WITHOUT REACTANCE***	***WITH REACTANCE***
1.	**Case 1**	77.8813	17.6982	18.6271
2.	**Case 2**	77.2622	17.5575	18.4790

Thus, the remaining distribution transformer load pattern is also changed step by step and the percentage voltage drop is been calculated for each distribution transformer by using MATLAB/code/program as given and the calculated results are been tabulated in table IV.

TABLE IV. VOLTAGE REGULATION OF THE REMAINING DISTRIBUTION TRANSFORMERS

SI. No.	% VOLTAGE DROP			
	TRANSFORMER CAPACITY (kVA)	***FEEDER CURRENT (Amps)***	***WITHOUT REACTANCE***	***WITH REACTANCE***
1.	500 kVA	77.26	17.55	18.47
2.	250 kVA	76.95	17.48	18.40
3.	100 kVA	77.26	17.55	18.47
4.	63 kVA	76.83	17.46	18.37
5.	250 kVA	77.75	17.66	18.59
6.	100 kVA	77.69	17.65	18.58
7.	63 kVA	77.44	17.59	18.52
8.	63 kVA	76.95	17.48	18.40
9.	250 kVA	76.05	17.28	18.18
10.	63 kVA	76.38	17.58	18.50

VI. CONCLUSION

By comparing both the results of case 1 and case 2, it is evident that there is reduction in the value of voltage regulation with re-allocation of load (i.e. load management).

Thus the following points can be gathered from diversity of load and load staggering,

- It is possible to reasonably improve the voltage regulation by changing the load timing to be loaded away from peak loading.
- No compensating devices are required to improve the tail end voltage which is an advantage of this scheme.
- Further, the load on the feeder is within limits, hence the quality of power is improved and better.
- This Novel Approach is recommended where the consumers are willing to actively participate into load management by slightly changing their energy usage pattern.

A. Abbreviations and Acronyms

- The abbreviation “IEEE” means “Institute of Electrical and Electronics Engineers”
- The abbreviation “M.Tech” means “Master of Technology”
- The abbreviation “i.e.” means “that is” and the abbreviation “e.g.” means “for example”
- The abbreviation “Al” means “Aluminium”
- The abbreviation “CosØ” means “power factor for an particular type of load”
- The abbreviation “Ckt” means “circuit”
- The abbreviation “%” means “percentage”
- The acronym “AC” means “alternating current”
- The acronym “CB” means “circuit breaker”
- The acronym “DT” means “distribution transformer”
- The acronym “kV” means “kilo volt”
- The acronym “kVA” means “kilo volt ampere”
- The acronym “kWh” means “kilo watt hour”
- The acronym “kVAh” means “kilo volt ampere per hour”
- The acronym “MW” means “mega watts”

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BIBLOGRAPHY

Pratapsingh Sarjerao Jadhav was born in Satara district Maharashtra, India in 1984. He has completed his Diploma in Electrical and Electronics Engineering form Government Polytechnic Belgaum, Karnataka, India in the year 2003. He also completed his Graduation, B.E in Electrical and Electronics Engineering from Angadi Institute of Technology and Management, Belgaum in the year 2013 and he is pursuing his Post Graduation, M.Tech degree in Power Systems Engineering from Jain College of Engineering Belgaum, affiliated to Visvesvaraya Technological University Belgaum, India. As he has a wide experience of four years in Transmission and Distribution of LT, HT, HVAC, EHVAC under IS 2026, also with Errection, Testing and Commissioning of 220kV substations. He has also served as Site Engineer under ABB for APDRP works, RLMS project in Karnataka and for Traction and load in Bhusawal, Maharashtra for Errection of substation and STATCOM for power factor improvement. He also has an Industrial experience of three years in Manufacturing, Quality Assurance and Testing of electrical machines under IS 4722. His research interest is in Power systems, Electrical machines and Industrial automation and robotics.