A Real Time Simulation Model for Transformer Load Balancing

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ABSTRACT:

This paper addresses the development of an average value based model, for the process variables of a spatially situated electric distribution system. The idea involves the continuous observation of the load currents in three different phases of a distribution transformer, fixation of its average values on real time basis, mathematical model development with the above average value as base factor. The validation of the so developed model is done by experimenting in a working system. The so developed average value based model could be utilized for balancing the loads of a distribution transformer. A simulation study is also carried out to emphasis the same.

KEYWORDS: Transmission system, Distribution system, Average value based model, base average value, variational part in base average value, remote switching unit.

1. INTRODUCTION:

In recent years, power quality has become an important issue for electrical power distribution systems. Several changes have occurred in different stages of electric distribution systems as a whole. Spatially distributed load over a wide area, spatially distributed concentrated load over a wide area leading to long feeders are the inherent characteristic of such systems. Such distribution electric networks may have unbalanced operating regimes mainly produced by the great number of single phase loads. This leads to unbalance resulting in excessive line voltage drops and power loss. Unbalanced currents produce unbalanced voltage drops in the three phases of the supply system .In the distribution and transmission electric networks; the main effect of unbalanced currents is the existence of additional power losses. As a result, the quality of power delivered to the consumer is not attractive.

It should also be noted that the degree of unbalance in distribution feeders is varying one-it changes with time of the day, day of the week etc. This implies that a static-one time reconnection of loads or reconfiguration of feeders will not solve the problem of unbalanced feeder currents. Quiet evidently some kind of dynamic balancing arrangements will go a long way in improving the quality of power delivered to the consumer.

Numerous researchers in the past, present were already in the line of load modeling and many suggestions are currently in the anvil. E Ortojann etal presented an approach for power distribution in hybrid power systems using an RMS (root mean squared) model for the electrical part of the system in combination with the set of differential equations to describe the dynamic behavior of the mechanical part of the system [1]. A three phase power system dynamic modeling based on the information about boundary components is presented in [2].Here the power system is divided in to a study system which can be a regional system and several external systems. The external system is a MIMO (Multiple Input Multiple Output) system and it is represented by Auto regressive model (ARX) and the analysis is made. An improved model for representing the voltage sensitive dynamic loads ,distribution system equivalents with load tap changers etc has been presented with specific selected operational study scenario of AEP Central AP company area[3].Dynamic equivalents of distribution systems including dynamics of electric loads and on load tap changer with reference to a radial distribution system and thereby developing an equivalent model is depicted in [4].Power system composite load dynamics is well represented in[5] whereas determination of dynamic load model parameters on the basis of secondary side measurements of 110/10KV transformer is the content of [6].The characterization of the distribution system load as a function of the substation voltages is done by Micheal .J.Gorman, Sehyan Civanlar in [7].The dynamic variation of the composite system load on distribution feeders is captured and the most effective substation voltage level is obtained. Model validation principle using hybrid dynamic simulation and an algorithm for obtaining optimal feeder configuration of a power system distribution network are represented in [8, 9] respectively. The dynamic load modeling of an Egyptian primary distribution system using neural networks is presented in [11].Here three load models for the primary distribution system are proposed and tested using artificial neural networks.

An accurate and flexible approach for building fuzzy load models of distribution transformer which could be used in transformer management and distribution network analysis is presented in [12] by Chang et al. Electric power distribution substation load modeling using dynamic load parameters estimation is the content of [13].The dynamic parameter estimation is developed using weighted least squared method in a recursive form. Lefebvre et al presented a physically load model for computing the electric load on residential distribution feeders and on distribution transformers [14].Parameter estimation and comparison of load models by developing a synthesis load model is presented in [15] by Chen et al. Detained end use modeling for distribution system analysis is depicted in [16].The approach helps to improve simple time invariant load models and develop multi state time variant load models.

The impacts of electrical loads on dynamic performances of wide area power system is analyses in [17] by Ju et al by developing wide area load modeling strategy. The electrical loads are firstly classified in to few categories using the component based load modeling method. According to the problems studied, the output variables of the power system are selected and the objective function is constructed using the data from wide area measurement system. Quintela et al presented a method to use static Var Compensators with four wire three phase loads to perform load balancing and reactive power compensation [18].As a result, any load connected to a three or four wire three phase system can be transformed to a balanced load with unity power factor even if it is single phase load. A paper which deals with the distribution unbalance and development of tangible relationships between the level of unbalance and cited consequences of the distribution networks is presented in [19] by Tavakoli and kashefi.

Even though sufficient quantities of work in the broad area of dynamic models of electric generation and distribution system variables are cited through the citations mentioned above, a serious study on the load variable dynamics with the specific intention of making the system a self balancing one is not commonly observed. It is towards this attempt the present work is intended. The continuous observation of the load currents in three different phases of distribution transformers, fixation of average values on real time basis, mathematical model development with the above average value as base factor is the ideology behind the paper. The validation of the so developed model is done by experimenting in a working system. A simulation study is also carried out to utilize the average value based model for balancing the loads of a distribution transformer..

2. SYSTEM DESCRIPTION

The power system network is viewed as a system which in turn is a combination of subsystems called generation, transmission and distribution as shown in Fig .1

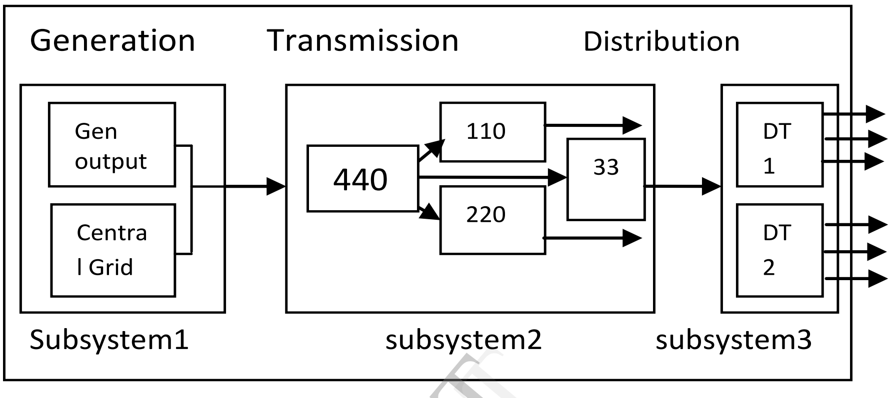

Fig 1

The lowest level of the hierarchical system, represented by subsystem3 in the fig 1 is the distribution transformer which can be viewed as a multiple input, multiple output system having input currents of same RMS magnitude and having four output currents with distinct RMS values. as shown in Fig 2.

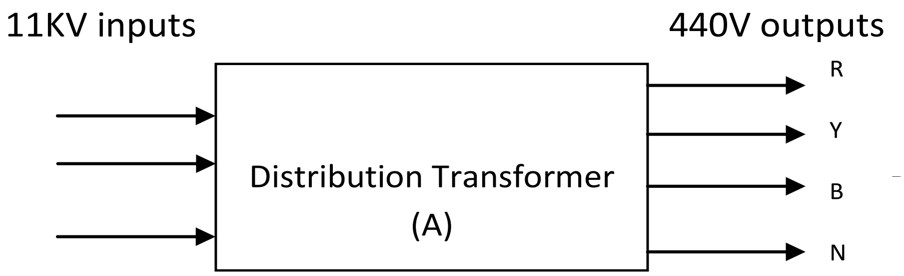

Fig 2

Each three phase outputs are normally identified by R, Y, and B. The dynamics of these R, Y, B output variables is obtained using the average value based model.

3.DEVELOPMENT OF AVERAGE VALUE BASED MODEL

Physically observed values (RMS) of the output currents (Ro, Yo, Bo) of the distribution transformer are indicated in Table 1. The variation in the values of load currents in the outputs is shown in Fig 3 to Fig.5 and that of input is shown in Fig 6.These figures shows the actual dynamics of the four distinct outputs (RMS).This dynamics is for a time period of 24 hours starting from 9:00AM on a particular day to 8:00AM the next day.

This characteristic is assumed to be similar for the further periods with same duration for the same system or in fact, this time duration is assumed as a representation for the further similar periodic durations.

	63 KVA Transformer				
	Input current (Ampere)	Output current (Ampere)			
Time	Ri =Yi =Bi	R phase (Ro)	y phase (Y0)	B phase (Bo)	Neutral (No)
9.00 AM	1.44	50	30	40	4
10.00 AM	1.5	55	30	40	8
11.00 AM	1.56	60	30	40	12
12.00 AM	1.68	65	35	40	16
1.00PM	1.62	55	35	45	3
2.00 PM	1.62	65	25	45	12
3.00 PM	1.62	60	30	45	7
4.00 PM	1.5	50	35	40	4
5.00 PM	1.68	55	40	45	4
6.00 PM	1.74	50	45	50	2
7.00 PM	1.74	50	45	50	2
8.00 PM	1.68	45	45	50	5
9.00 PM	1.62	50	40	45	1
10.00 PM	1.68	55	45	40	11
11.00 PM	1.68	60	40	40	13
12.00 PM	1.74	50	45	50	2
1.00 AM	1.8	55	45	50	1
2.00AM	1.8	60	40	50	3
3.00 AM	1.74	65	35	45	11
4.00 AM	1.74	60	40	45	8
5.00 AM	1.62	60	35	40	12
6.00 AM	1.56	55	35	40	8
7.00 AM	1.44	50	30	40	4
8.00 AM	1.44	50	30	40	4

Table 1: Observed values of a Distribution Transformer

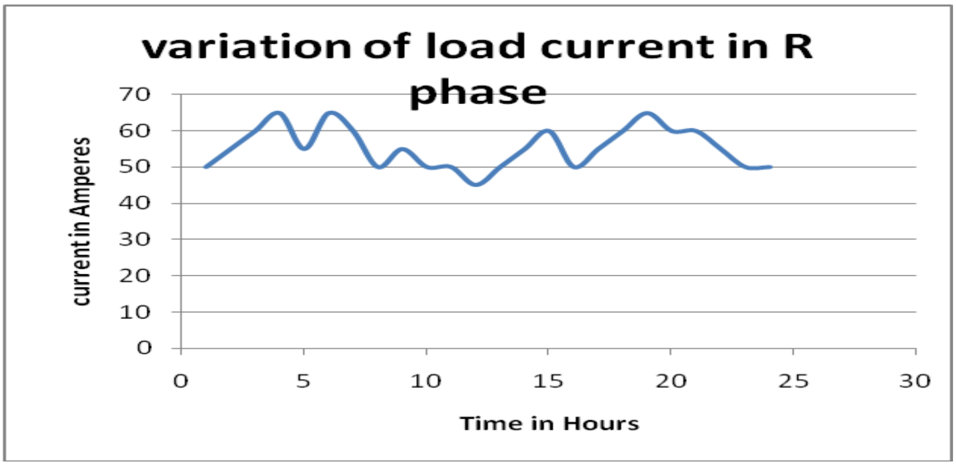

Fig 3

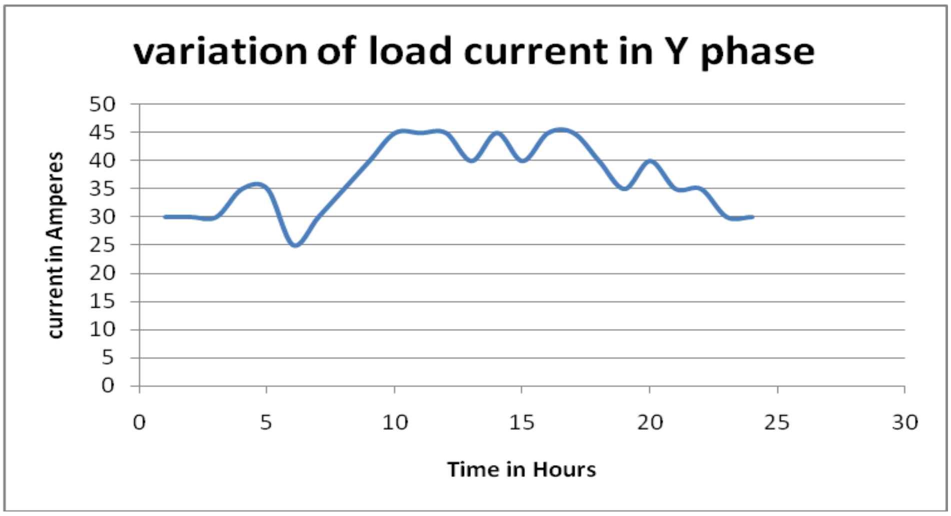

Fig 4

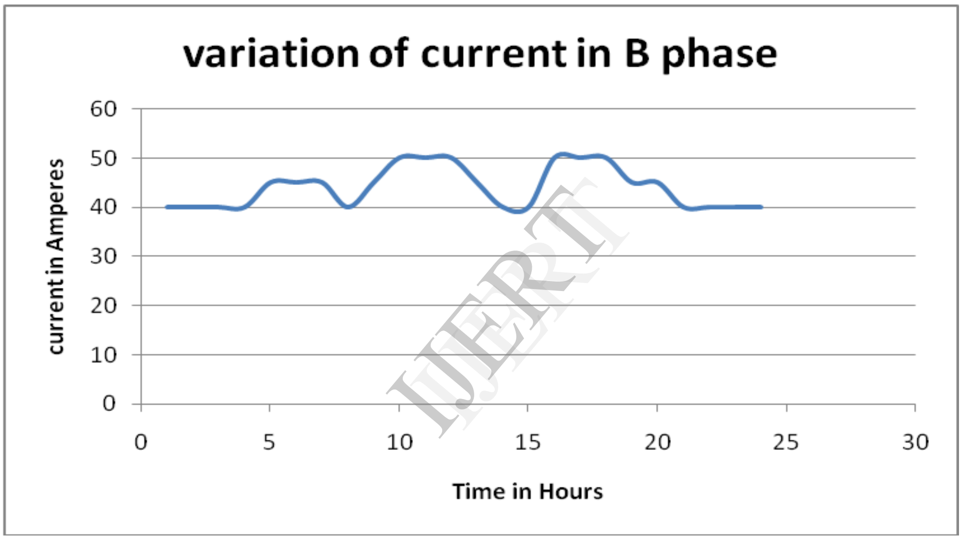

Fig 5

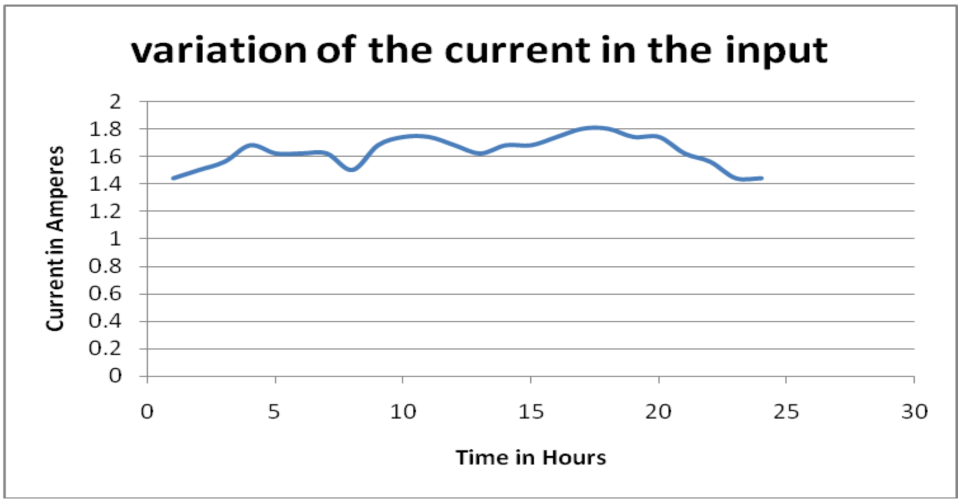

Fig 6

A linear mathematical model for the above observed dynamics is formulated on the assumption that the dynamic variable is a linear combination of a base average value and infinite number of hierarchically considered variational terms [10]. These variational terms are called variational part in base average value, second variational part in the base average value and so on. The procedure for deriving these factors is explained in detail as follows.

a) Identical Average value sectors:

On examining the observed values corresponding to the output (Ro) indicated in Table 1 it is noticed that the average values(average of R MS values of the currents) of certain sectors are the same. These sectors are called identical average value sectors indicated as Table 2, 3, 4. The so detected average values are shown in Table 5 corresponding to the sectors 1,2,3 which are named as primary sectors.

60
65
60
60
55
50
50

Table 2:

50
55
60
65
55
65
60
50
55

Table 3

50
55
60
50
55
60
65
60
60
55

Table 4 Primary sectors

	Average value of the output (Ro) (Primary averages)	Average value of the input
Sector1	57.14	1.62
Sector2	57.22	1.58
Sector 3	57	1.698

Table5: Primary averages

b) Secondary Sectors:

	Secondary sectors	Secondary averages of the output (Ro)
Primary sector1	Sector1	61.25
	Sector2	51.6
Primary sector 2	Sector 3	57
	Sector4	57.5
Primary sector 3	Sector 5	55
	Sector 6	60

Table 6: Secondary sectors

For further experimentation with the observed values inside the primary sectors, inner secondary sectors indicated in Table 6 exists which yields the average value which are slightly and independently different from the average value of the primary sectors. They are named as secondary averages. This is indicated in Table 7.

Secondary sectors					
from primary1		from primary2		from primary3	
60	55	50	65	50	65
65	50	55	60	55	60
60	50	60	50	60	60
60		65	55	50	55
		55		55	
				60	

Table7:Secondary averages

C) Tertiary sectors

Similarly, some tertiary sectors are identified inside each of the above secondary sectors which further yields slightly different average values from the respective average values of the secondary sector. They are termed as tertiary averages. The tertiary sectors and tertiary averages are represented in Table 8 and 9 respectively.

from primary1			
from secondary1		from secondary2	
60	60	55	50
65		50	
60			

from primary2			
from secondary3		from secondary4	
50	65	65	55
55	55	60	
60		50	

from primary3			
from secondary5		from secondary6	
50	55	65	55
55	60	60	
60		60	
50			

Table 8:Tertiary sectors

		Tertiary sectors	Tertiary averages of the output
Primary sector1	secondary sector1	Sector1	61.6
		Sector2	60
	secondary sector2	Sector3	52.5
		Sector4	50
Primary sector2	secondary sector3	Sector 5	55
		Sector6	60
	secondary sector4	Sector7	58.3
		Sector8	55
Primary sector3	secondary sector5	Sector 9	53.75
		Sector10	57.5
	secondary sector6	Sector11	61.6
		Sector12	55

Table 9 Tertiary averages

4. DERIVATION OF INPUT-OUTPUT RELATIONSHIP

Output dynamics can be considered a linear combination of components involving a base average value , Iavg, a variational part over the above average value, Δ Iavg, a factor containing variational part in Δ Iavg, i.e. ,Δ^2 Iavg, and so on[10]. It can be stated in another way that the output is a combination of a base average value and infinite number of hierarchically considered variational terms. To make it more clearly, these variational terms must be multiplied by factors (M_1,M_2,M_3………) to take care of the effect of variable structure or the input-output relationship can be represented empirically as

$$B\,Qavg = M_1 Iavg + M_2 \Delta Iavg + M_3 \Delta^2 Iavg + \ldots \quad (1)$$

Strictly speaking, the input part also has to be considered as a summation of infinite number of terms involving a base value and subsequent variational terms. But to avoid practical complexity only one term i.e. base term alone (Qavg along with the factor B) is considered for the input dynamics.

This approach is somewhat similar to the dynamic models described in [10].The main difference that occur with that described in [10] is that the present argument is based upon an average value whereas the one in [10] is treated mainly taking time as the base.Again it is assumed that the variational terms at the output is restricted up to two terms along with the base value and constant which are derived or formulated from directly measured RMS values of the output variables.ie equation (1) gets modified to

$$B\,Qavg = M_1 Iavg + M_2 \Delta Iavg + M_3 \Delta^2 Iavg \quad (2)$$

In the light of the above explanations, the input – output relationships of the distribution system can be stated as under:

B_1 QavgR=M_1IavgR+$M_2\Delta$IavgR+$M_3\Delta^2$IavgR (2.a)

B $_2$QavgY=M_4IavgY+$M_5\Delta$IavgY+$M_6\Delta^2$IavgY (2.b)

B_3 QavgB=M_7IavgB+$M_8\Delta$IavgB+$M_9\Delta^2$IavgB (2.c)

Step1:

Procedure for finding the variational parts

The steps to be followed to obtain the variational parts are as under:

1. To find ΔI avg:
   a. Obtain the average value of the primary sector.
   b. Divide the primary sector into secondary sectors and find the secondary averages.
   c. Obtain the differences between the primary averages and the secondary averages.
   d. The averages of these differences are Δ Iavg.

2. To find Δ^2I avg:
   a. Divide the secondary sectors in to tertiary sectors.
   b. Determine the tertiary averages.
   c. Obtain the differences between the secondary averages and tertiary averages.
   d. The average of these differences are Δ^2I avg.

The above procedure is adopted to obtain the variational parts of the primary sectors and the equality statements corresponding to this combination of primary sectors are obtained as follows

B 1.62=$M_1$57.142-$M_2$0.684-$M_3$0.416 (3)

B 1.58=$M_1$57.22+$M_2$0.027-$M_3$0.166 (4)

B1.698=$M_1$57+$M_2$0.5-$M_3$0.5208 (5)

Where M_1, M_2, M_3 represents variation in structure at the output.

B represents variation of structure in the input.

57.142 = base average value of the output in the primary sector1.

57.22 = base average value of the output in the primary sector2.

57 = base average value of the output in the primary sector3.

-0.684 = Variational part over and above the average value 57.142

0.416 = Variational part over and above the change in average value -0.684.

1.62 = base average value of the input corresponding to the primary sector in the output.

Step 2:
Solution of Equations (3), (4), (5) results in the values of constants M_1/B, M_2/B, M_3/B.

Step 3:
Reproduction of the equations (3),(4),(5) in terms of general variable corresponding to Iavg, Δ Iavg , Δ^2 Iavg. i.e the equality statement can be reproduced as

$$Qavg = 0.0267Iavg+0.043\Delta Iavg-0.291\ \Delta^2 Iavg \quad (6)$$

Similarly the models are identified for the other two variables (Y phase and B phase) of the distribution transformer and are obtained as follows.

$$Q(Y) = 0.049Iavg(Y)+0.124\Delta Iavg(Y)-0.014\Delta^2 Iavg(Y) \quad (7)$$

$$Q(B) = 0.037Iavg(B)-.024\Delta Iavg(B)+0.00141\Delta^2 Iavg(B) \quad (8)$$

5.IMPLEMENTATION OF THE MODEL FOR LOAD BALANCING

In earlier section, it is already stated that the average value based model can be used for balancing the loads. But here the observations made are on a real electric distribution system running for public services. Hence implementation in the real sense by adding additional hardware and software were not permitted legally. Because of these legal problems, the experimental verification is done by simulation approach.

5.1 Conditions for load balancing

In the earlier section, the input output relationships for the load currents in three phases of the distribution transformer were obtained. As it is seen from the Table 1 that the output load currents in all the three phases are not balanced, next step is to fix an average value as the reference for balancing. This reference value is fed to the controller for comparing the currents of three phases and make appropriate switching actions with the help of relays so as to make the load currents of three phases balanced.

5.2 Setting up of reference average value.

The steps followed for setting up of reference value are as mentioned below:

- Find out the Iavg, Δ Iavg and Δ^2 Iavg from the rms values of load currents for a particular zone/period for all the three phases.
- Substitute these values in the best models obtained for all the three phases.
- Take the average of all these three values and that is taken as the set average value for that particular zone.

The best models were identified for the three phases of the above transformer, and hence the reference value for balancing could be set using the procedure mentioned earlier. For this the total duration of 24 hours can be divided in to three different zones as from 6.00 AM to 6.00 PM as one zone, 6.00 PM to 11.00 PM as the second zone and from 11.00 PM to 6.00 AM as the third zone. The reference value will be different in different zones and hence the reference values have to be calculated separately for the three zones. A programming module is developed for the calculation of the reference value and thereby the variations of the instantaneous load currents from the reference value are obtained as shown in Table 10.

Reference value obtained for 1st zone: 45 A

Reference value obtained for 2nd zone: 48 A

Reference value obtained for 3rd zone: 43 A

Time in Hours	Variations of output currents from the reference value		
	R	Y	B
9.00 AM	-7	13	3
10.00 AM	-12	13	3
11.00 AM	-17	13	3
12.00 AM	-22	8	3
1.00PM	-12	8	-2
2.00 PM	-22	18	-2
3.00 PM	-17	13	-2
4.00 PM	-7	10	3
5.00 PM	-10	5	0
6.00 PM	-5	0	-5
7.00 PM	-5	0	-5
8.00 PM	0	0	-5
9.00 PM	-5	5	0
10.00 PM	-10	0	5
11.00 PM	-15	5	5
12.00 PM	-5	0	-5
1.00 AM	-10	0	-5
2.00AM	-12	8	-2
3.00 AM	-17	13	3
4.00 AM	-12	8	3
5.00 AM	-12	13	8
6.00 AM	-12	8	3
7.00 AM	-7	13	3
8.00 AM	-7	13	3

Table 10

Based on the variations, the programming module will adjust the loads between the phases and the probable balanced states are derived as follows in Table 11

Time in hours	Unbalanced states			Output currents under probable balanced state		
	R	Y	B	R	Y	B
9.00 AM	50	30	40	43	37	40
10.00 AM	55	30	40	43	42	40
11.00 AM	60	30	40	44	43	43
12.00 AM	65	35	40	54	43	43
1.00PM	55	35	45	47	43	45
2.00 PM	65	25	45	47	43	45
3.00 PM	60	30	45	47	43	45
4.00 PM	50	35	40	43	42	40
5.00 PM	55	40	45	50	45	45
6.00 PM	50	45	50	50	45	50
7.00 PM	50	45	50	50	45	50
8.00 PM	45	45	50	45	45	50
9.00 PM	50	40	45	45	45	45
10.00 PM	55	45	40	50	45	45
11.00 PM	60	40	40	50	45	45
12.00 PM	50	45	50	50	45	50
1.00 AM	55	45	50	55	45	50
2.00AM	60	40	50	52	48	50
3.00 AM	65	35	45	49	48	48
4.00 AM	60	40	45	49	48	48
5.00 AM	60	35	40	48	45	42

6.00 AM	55	35	40	44	43	43
7.00 AM	50	30	40	43	37	40
8.00 AM	50	30	40	43	37	40

Table 11

A simulation graph showing the variations of load currents in all the three phases of the above considered distribution transformer under the unbalanced and probable balanced states are obtained as shown in Fig 7 and Fig 8 respectively.

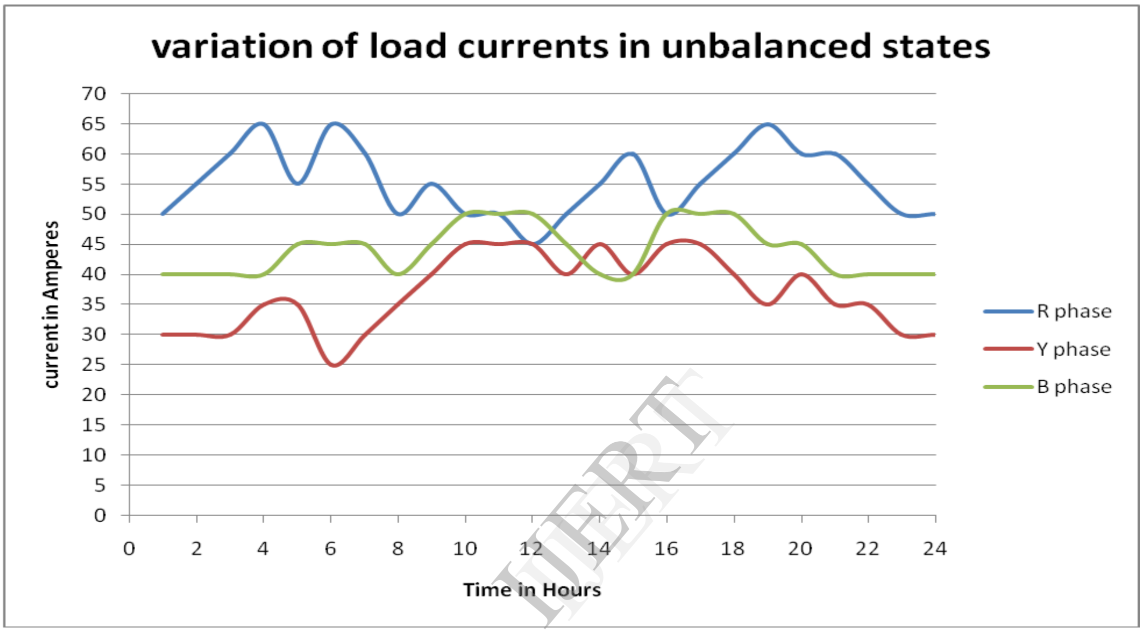

Fig 7

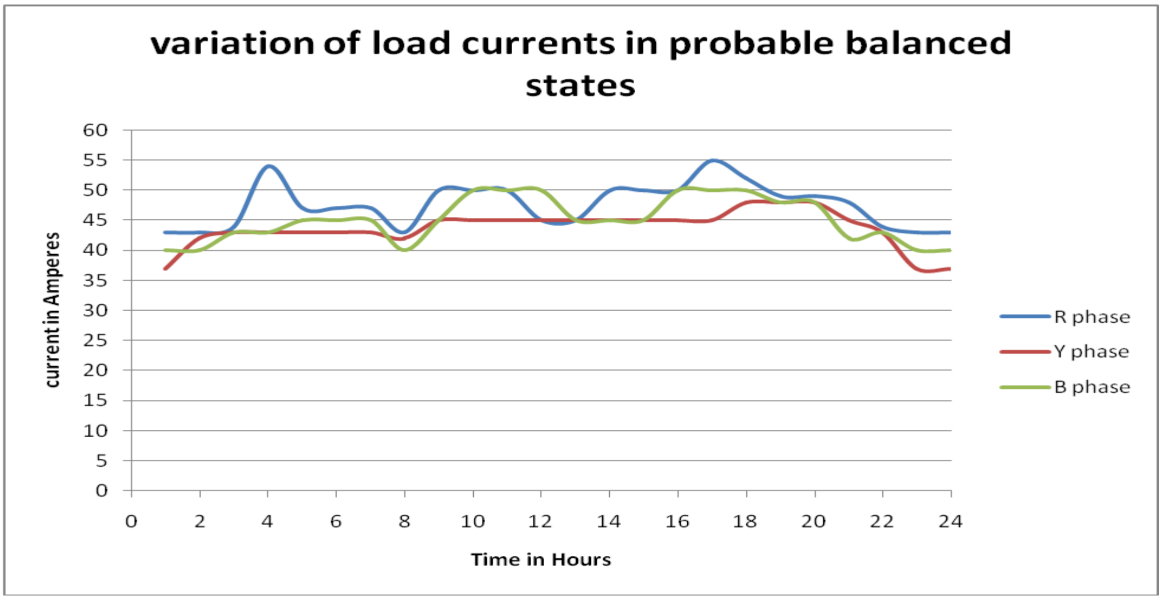

Fig 8

6. CONCLUSION

An average value based model has been developed in this paper. The requirements of this approach are a set of readings from the real time system to calculate the base average value and the variational components. The derived model is an input-output relationship. The model uses only RMS values of the input-output variables so that it can be monitored and utilized for making the system a self balancing one. Based on the model developed, a reference value is set up for balancing. . This reference value is fed to the controller for comparing the currents of three phases and make appropriate switching actions with the help of relays so as to make the load currents of three phases balanced. A simulation model for the above is developed and the variations of the load currents under unbalanced states and the probable balanced states are plotted.

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