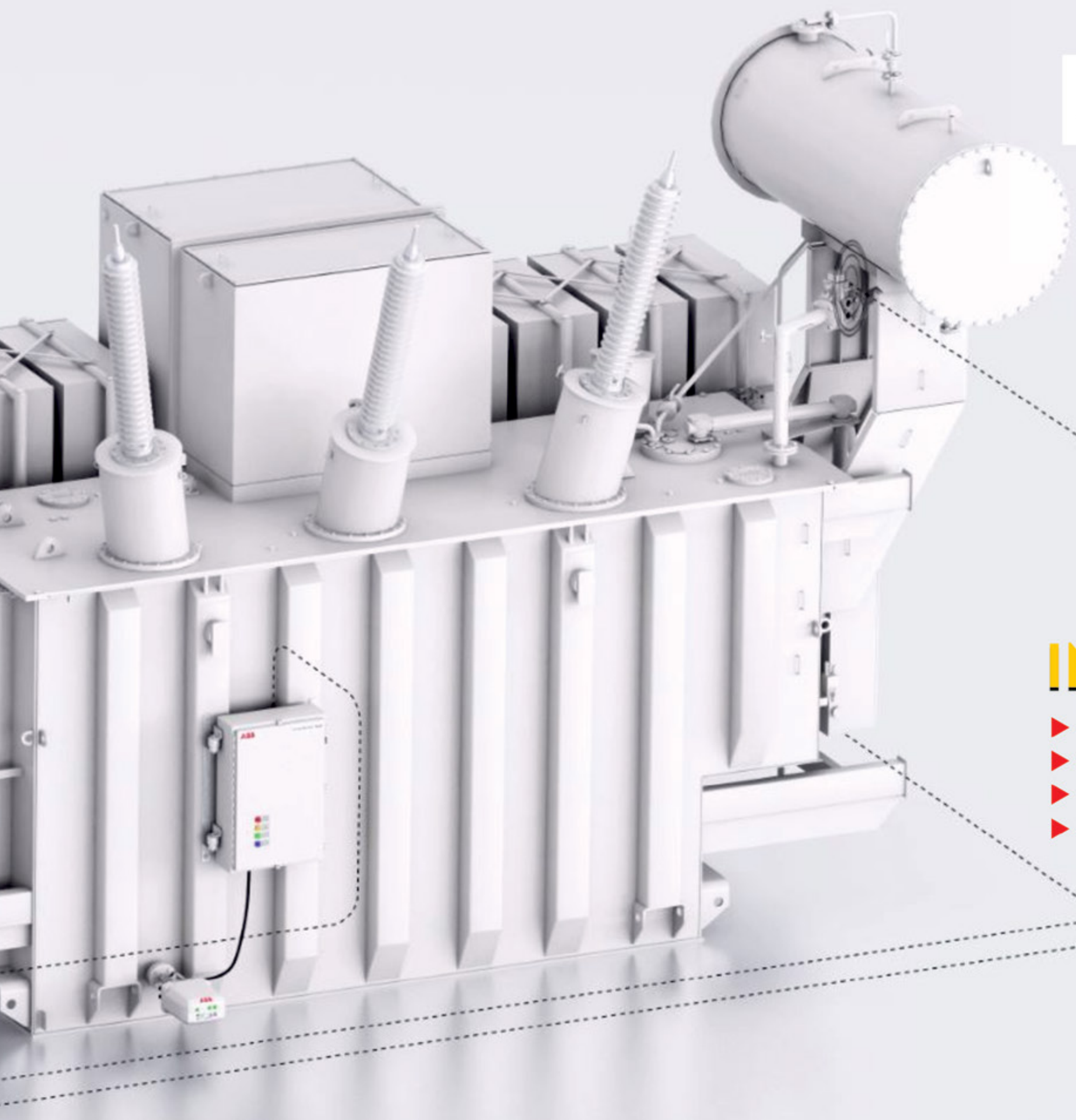
September 2022 Volume XII Issue III R.N.I. No. DELENG/2011/39089 Pages 92 ₹ 80/-

ELECTRICAL MIRROR

An Outlook of The Electrical & Power Industry

POWER TRANSFORMER

www.electricalmirror.net



INSIDE

- T & M Instruments
- T & D
- Renewable Energy
- Floating Photovoltaics

Cover Story

POWER TRANSFORMERS

ELECTRICAL MIRROR
An outlook of the Electrical & Power Industry

"HARMONICS"- ATTRIBUTE TO PREMATURE FAILURE OF DISTRIBUTION TRANSFORMERS

Synopsis:

Unlike Voltage-Sag, Voltage-swell, Interruptions, Voltage-unbalance Voltage-fluctuations, Transient conditions due to switching & lightening surges, etc. which are short lived, Harmonics is the component which shall neither die nor vanish from the Power Systems over a period of time unless otherwise harmonic filters are used. Harmonics are responsible for deteriorating the Power Quality.

Many Distribution Transformers installed in the Commercial & office complexes, Malls etc fail prematurely. Most of the Distribution of Power Supply Utilities procure DTRs (Distribution Transformers) confirming to the IS: 1180(part-1)-2014[1] /IEEEC57.12.20-2017[2] irrespective of the location, where they are to be installed at . The causes of failure are generally reported to as over-loading or short-circuit in L.T. network in the complexes etc whereas the cause of failure of such DTRs is predominantly due to Harmonics only.

The Distribution Transformers confirming to IS: 1180(part-1) -2014[1]//IEEEC57.12.20-2017[2] are manufactured to feed linear loads; however, they are also capable of feeding the non-linear loads which give rise to Harmonic distortion in sinusoidal wave to the tune of TDD (Total Demand Distortion) of 5% as stipulated in the BEE (Bureau of Energy Efficiency, India) Std. and IEEE Std.-519.-2014[3]

The authors has narrated the ill-effects of Harmonics attribute to premature failure of DTRs in this Article and has also suggested remedial measures thereof.

Key words and Acronyms: DTR (Distribution Transformer),THd (Total harmonic Distortion),TDD (Total Demand Distortion),PCC(Point of Common Coupling) K-Type Transformer, Non-linear Load (whose impedance continuously varies with its applied voltage Cycle), PQ (Power Quality).

1.0 Introduction: Prior to year 2018, IEEE std1159-1995 (Recommended practice for monitoring Electric power quality) was followed in India, however, BIS has now defined the "DISTRIBUTION SYSTEM SUPPLY VOLTAGE QUALITY vide IS: 17036- 2018.[4] Now, It is mandatory on the part of Distribution Utility to abide by this IS and maintain;

a) Frequency.
b) Magnitude
c) Wave form and
d) Symmetry of line voltages

a) (i) Supply frequency limits of the source connected to synchronised system + 4% / - 6%.however frequency range for the whole country as defined in IEGC (Indian Electricity grid code) as 49.9 to 50.05Hz. w.e.f. 17th Feb. 2014. as per CERC's which is within the stipulations

(ii) Supply frequency limits of the source without having connection to Synchronised system ±15% of 50Hz

b) Voltage Magnitude in the band of Un±10 %.

c) Low voltage harmonic distortion Limits.

Parameter	*Special application	General system	#Dedicated system
THD	3.5%	5%	10%

Note: * Includes Hospitals and Airports.
Exclusively dedicated to converter loads.

d) Supply Voltage Unbalance: Ratio of rms value of negative Phase sequence component (fundamental) to rms value of positive phase sequence component (fundamental) of supply voltage 95% of each period of one week should be ≤2%

1.1 Following are the voltage wave shapes/Voltages which pollute the Power Supply to the Consumers;

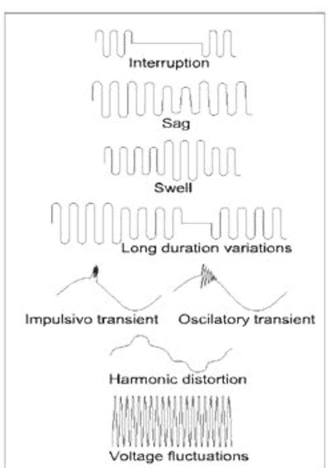


Fig.1: Voltage wave shapes / voltages which pollute the Power Supply to the Consumers.

In the present era/scenario, though the technology in the field of Electronics, Computer Science, IT, Lighting & illumination etc have grown by leaps and bounds, enabling every office, commercial stalls etc to save on time, money and manpower using electronic gadgets which are predominantly non-linear electronic gadgets like; Switched mode Power supplies (SMPS), Variable speed motors and drives, UPSs(Un-interrupted Power Supplies), PCs(Personal Computers), Laser printers, Photocopiers, FAX machines, Battery chargers, Florescent Light Ballasts etc however, the irony is that, all these electronic modern gadgets in-turn pollute the power supply by producing Harmonics contrary to maintaining PQ .

Single phase non-linear loads are prevalent in the modern offices and commercial complexes which are responsible for giving rise to harmonic currents.

2.0. What Causes Harmonics?

Harmonics are generated by electronic equipment with non-linear loads drawing in current in the form of abrupt pulses. These short pulses cause distorted current waveform which in-turn cause Harmonic current to flow into the power system.

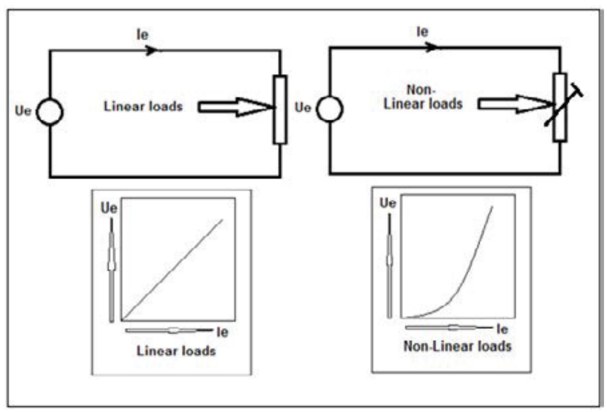


Fig.2: Concept of linear and non-linear loads in a circuit.

2.1 Harmonics Waveforms:

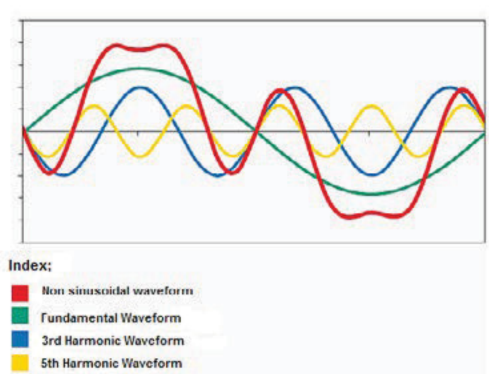


Fig. 3: Harmonic Waveform [5]

The above figure (Fig no.3) depicts the distorted non-sinusoidal wave form which is the resultant waveform of fundamental waveform, 3rd harmonic & 5th harmonic wave forms.

2.2 Voltage & current profile of Linear & Non-linear loads;

Sample wave forms of Linear and non-linear loads are depicted in fig.4 & 5 [6]

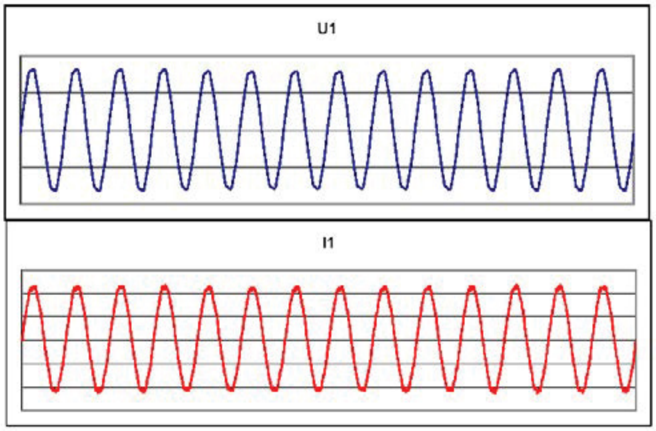


Fig. 4 : Voltage and current profile of linear load(Conventional bulb).

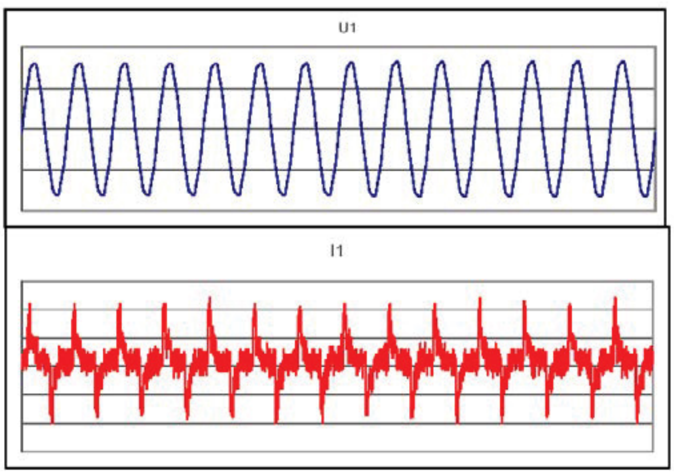


Fig. 5: Voltage and current profile of non-linear load (CFL).

Harmonics degrade the PQ level and also efficiency of the Distribution Transformers feeding the load particularly in the office complexes and commercial complexes.

Following gadgets/systems are designated as non-linear loads on a Power-system/ Transformer which produce harmonics:

Switched Mode Power supplies (SMPS), Variable speed motors and drives, UPSs (Un-interrupted Power Supplies), PCs (Personal Computers), Laser printers, Photocopiers, FAX machines, medical test equipment, Battery chargers, Florescent Light Ballasts etc.

Single phase non-linear loads are prevalent in the modern offices and commercial complexes.

2.3 Sample Harmonic profile of a consumer load;

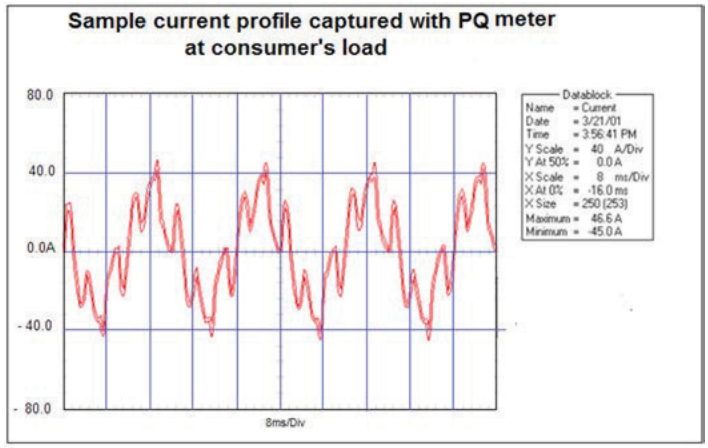


Fig.6.Harmonic current Profile

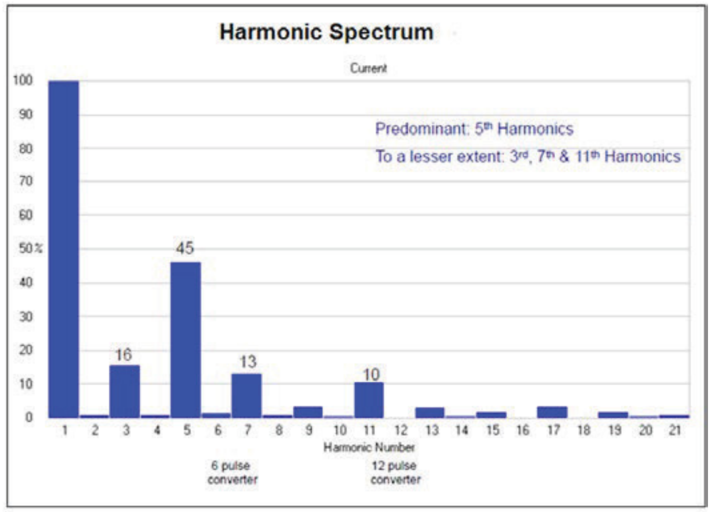


Fig.7 Harmonic Spectrum of Fig.6.

3.0 THD (Total harmonic Distortion) and TDD (Total Demand Distortion);

The Total harmonic Distortion (THD) as a measurement indication of signal deviation from a pure sine wave.

i)Current Distortion;

$$THD(I) = \sqrt{\sum_{n=2}^{40} I_n^2} \Big/ I_1$$

Where n=harmonic no, In= Amplitude of Current at nth Harmonic, I1= Amplitude of fundamental Current.

ii) Voltage distortion;

$$THD(U) = \sqrt{\sum_{n=2}^{40} U_n^2} \Big/ U_1$$

Where n=harmonic no, Un= Amplitude of voltage at n th Harmonic, U1= Amplitude of fundamental voltage.

iii) Total Demand Distortion;

$$TDD(I) = \sqrt{\sum_{n=2}^{40} I_n^2} \,/\, I_{MaxDemand}$$

Where I max Demand

4.0 What are triple – N Harmonic Components?

- Distorted waveform in Power Systems contains only odd harmonic components,
- Odd Harmonic phase sequence rotations are shown here under;
  - Harmonics of the order h = 1, 7, 13,… are purely positive sequence.
  - Harmonics of the order h = 5, 11, 17,… are purely negative sequence.
  - Triple N Harmonics (h = 3, 9, 15, …) are purely zero sequence. Thus, are co-phasal.

4.1 Derivation of sequence rotation of odd harmonic currents [6];

Harmonics	A	B	C	Phase rotation
Fundamental	0^0	120^0	240^0	(+)Ve
3rd	0^0	3x120^0 (0^0)	3x240^0 (0^0)	Zero
5th	0^0	5x120^0 (240^0)	5x120^0 (0^0)	(-)Ve
7th	0^0	7x120^0 (120^0)	7x240^0 (0^0)	(+)Ve
9th	0^0	9x120^0 (0^0)	9x240^0 (0^0)	Zero
11th	0^0	11x120^0(240^0)	11x240^0 (120^0)	(-)Ve
13th	0^0	13x120^0(120^0)	13x240^0 (240^0)	(+)Ve
15th	0^0	15x120^0 (0^0)	15x240^0 (0^0)	Zero
17th	0^0	17x120^0(240^0)	17x240^0 (120^0)	(-)Ve

Table 2

4.2 Phasor representation of Odd- harmonic currents;

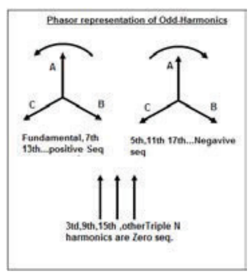


Fig.8: Phasor representation of odd –harmonic currents.

5.0 Current distortion Limits as specified by IEEE 519-2014(120 V to 69 kV);

Maximum harmonic current distortion in % of IL						
Individual harmonic order (odd Harmonics)						
ISC/IL	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h < 50$	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20< 50	7.0	3.5	2.5	1.0	0.5	8.0

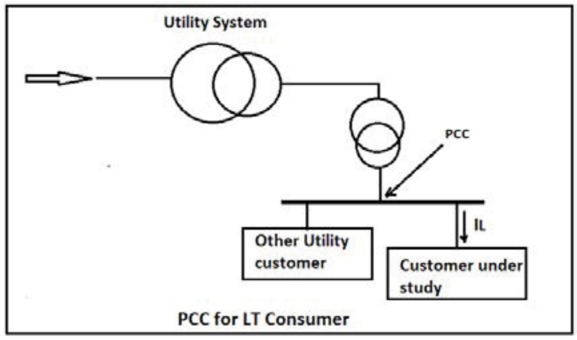


Fig 9B

6.0 Detrimental effects of Harmonics (Generalised):

Power systems can accommodate a certain level of harmonic currents but shall experience problems when the current harmonics are enhanced. As these higher frequency harmonic currents flow through the power system at load side as well as on PCC (Point of Common Coupling) side. The ill-effects caused by the harmonics are as follows;

- Flaring of Fire in multi-storied residential complexes.
- High voltages and circulating currents caused by harmonic resonance.
- Equipment malfunctions due to excessive voltage distortion.
- Increased internal energy losses in connected equipment, causing component failure.
- Shortening of Life-expectancy of Power equipment.
- False tripping of branch circuit breakers
- Metering errors.
- Fires in wiring and distribution systems.
- Lower system power factor, resulting in penalties on monthly utility bills.
- Overheating of electrical distribution equipment, cables and Distribution Transformers.
- Increase in neutral current.

6.1 Detrimental effects of Harmonics on the 3 Ph Distribution Transformers;

A) Increase in losses in the Distribution Transformers.

i) Increase in iron-losses;

The iron-losses are due to hysteresis & eddy current phenomenon. The iron-loss due to hysteresis is proportional to the frequency and the iron-losses are caused by the eddy currents depend on the square of the frequency.

ii) Increase of copper-losses and stray flux losses;

Increase in Copper-loss is due to increased square of the harmonic current and also skin effect associated high-frequency harmonics.

50<100	10.0	4.5	4.0	1.5	0.7	12.0
100< 1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Table 3.

- ISC =Max short Current at PCC (Point of Common Coupling)
- IL = Max. Demand Load current (fundamental frequency Component) at PCC.
- TDD=Total Demand Distortion, Harmonic current Distortion in % of max Demand load current (15 or 30min Demand.)
- The odd harmonic range is given from 3 to <50.Say for example: 23≤h<35 that means odd harmonics between the range 23rd to 35th.
- point of common coupling (PCC): Point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the considered installation.

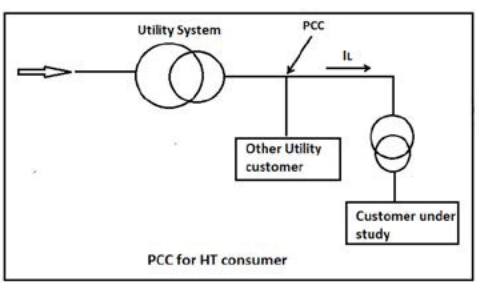


Fig.9A

iii) Presence of Harmonic circulating currents in the Delta windings.

As most of the Distribution and Sub-transmission Transformers in the DISCOMs and Distribution Utilities in India are Delta-Star wound ones. Though the third harmonic components are prevented from propagating to upstream network of the Power supply system, however due to circulation of 3rd harmonic and triple N harmonic currents in the delta winding gives rise to heating of the Distribution Transformers resulting into reduction in the life expectancy thereof.

B) Increase in Neutral Current:

i) 1-phase loads are fed from Phase & Neutral. Unfortunately, 1-phase non-linear loads give rise to very high triple-N harmonic currents. In fact, they are odd multiples of 3 times the fundamentals. Since Triple- N harmonic currents (h = 3, 9, 15, …) are purely zero sequence currents, thus they pass through the neutral of Star connected Distribution Transformers in addition to normal 1-phase load currents

ii) Neutral Current due to 3rd Harmonics;

The wave shape of 3rd Harmonic current in the neutral is depicted by N-wave in the fig.10.

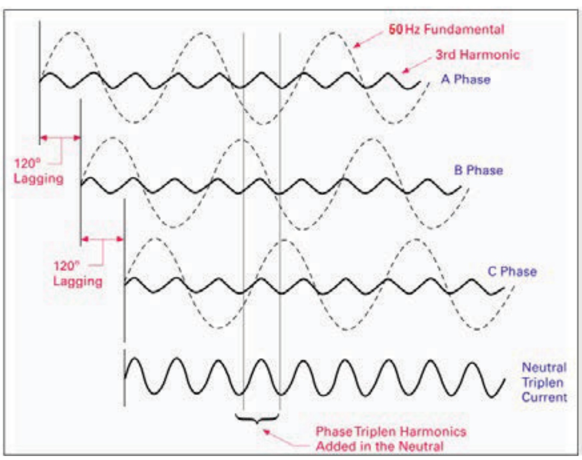


Fig. 10: Wave form of Triple N harmonic current.

It may be noted that when any non-linear 3 phase load is fed through a 3 phase supply, then in addition to the 3-phase load currents there will be always 3rd and triple N harmonic currents through the neutral as shown in the fig.10.

Further, if one or two-phases to ground fault occurs, the triple–N harmonic component shall add to the earth-fault current ie 3 I zero which are inherently zero sequence, raising the neutral current much higher.

6.2 Hazards due to above:

i) Over a period of time due to excessive heating of the Distribution Transformers the life expectancy reduces by half with every 6OC. rise in temperature between 80OC to 140OC in case of mineral oil filled Distribution Transformers as stipulated in IS: 6600-1972 and IS: 2026 (Part 7)-2009

ii) Threat of fire hazard in the office complexes, residential complexes or Commercial complexes like shopping malls etc cannot be ruled out.

Fig 11: Such fire in the building complex may be because of fire in the neutral conductor of the DTR, attributed by Harmonics in the Electricity supply system.

7.0 Remedial measures:

1) The Distribution Utilities should monitor with PQ analyser from time to time if any consumer is exceeding the limit beyond as that mentioned in the Table 3 against stipulation in IEEE Std.519 (2014) at the PCC, failing which necessary penalty may be levied on him.

2) To avert pre-mature failures of the transformers procured confirming to IS: 1180 (part 1), it is essential to monitor the winding temperature of the DTRs and restrict the load on the same to the tune of say 70% of the capacity thereof. Thus, the cost of procurement of the DTRs shall increase.

Note:a) Distribution Transformers confirming to IS: 1180 (part-1) are capable of feeding linear loads only.

b) It a was established by experiments etc as stated in ANSI/ IEEE 57-110 that a de-rating of 70% of the transformer capacity is required to be done in case the Transformers manufactured, to feed linear loads are utilised for feeding Harmonic loads.

3) *Use of K-rated transformers, which are developed to carry triple N harmonics created due to the use of on-linear loads. Such transformers, though do not remove harmonics from the power supply but are made robust enough with increased neutral conductor size to withstand the expected hazards which otherwise a Distribution transformer of the same rating manufactured in confirmation to IS: 1180 (Part-1) shall not sustain.

*Note: Salient points regarding K-rated transformers is narrated in Cl. 8.0 and algorithm for calculation of K -factor is narrated in Cl.9.0.

2) In the present day senario, the existing DistributionTransformers in the Office and Commercial complexes may be rertofitted with Natural or Synthetic Ester fluids which have flash point >3000 C as against 1400C of conventional mineral oil, with neutral return cable capable of carrying double the Phase current.

3) Use of Harmonic Filters.

8.0 What are K-Type transformers:[8] UL (Underwriters Laboratories-A Global scientific Laboratory which issues Standards for equipment for equipment safety) has established K-factor ratings in the Std. UL1561: As K-1,4,9,13,20,30,40 & 50. Such, Transformers have the following salient features

(i) Neutral connection leads are capable of carrying 150 to 250% times of current carrying capacity that of phase connection leads.

(ii) Smaller parallel windings on the secondary side of the transformers to compensate for skin effect associated with high frequency harmonics.

(iii) Transposed delta winding conductors.

(iv) Electrostatic shielding between primary and secondary winding.

The actual K-rating transformer describes the ratio of non-linear load to linear load it can handle. As the amount of non-linear load increases in respect to linear load higher K-rated transformers shall be required as detailed here under;

- K-1 Transformer is capable of feeding 100% linear load only.
- K-4 Transformer shall handle100% linear+50% non-linear load.
- K-13 Transformer shall handle100% linear+100% non-linear load.
- K-20 Transformer shall handle100% linear+125% non-linear load.
- K-30 Transformer shall handle100% linear+150% non-linear load.

9.0 Algorithm for calculation of K-factor [9];

$$K = \frac{\sum_{h=1}^{hmax}(f^2h.h^2)}{\sum_{1}^{hmax}(f^2h)} K = \frac{\sum_{h=1}^{hmax}(f^2h.h^2)}{\sum_{1}^{hmax}(f^2h)}$$

Where fh is the frequency in Hz of harmonic h.

10.0 Conclusion;

a) Strict monitoring by Distribution Utilities for limiting TDD of each consumer as defined in the IEEE 519.

b) For averting failure of conventional Distribution transfromers installed for feeding office comlexes and commercial complexes, loading up to 70% is recommended ie for meeting any load demand, higher capacity DTRs are to be Installed.For procurement of such higher capacity Transformers,enhanced financial burden has to be borne by DISCOMS & Distribution Utilities .

Example:If the demand is 200KVA then adequacy of capacity would be;

200/0.70=285.71KVA,

the nearest rating available is 300 KVA therefore instead of 200KVA ,a 300KVA Distribution Transformer is recommended to be installed.

c) Considering the above discussion, it is felt that the DISCOMS and Disribution Utilities in India must procure K-13 rating transformers for the office complexs and commercial complexes, wherein the balanced neutral is equal to un-balanced neutral current.The neutral current in such transformers was caluculated as 173% of the phase current {ref:para;9.0,2 (b)} Therefore in this Distribution Transformer the neutral conducer size is provided such that it can carry 200% of the Phase current.

d) In the present day senario, the existing DTrs in the Office and Commercial complexes may be rertofitted with Natural Ester fluids which have flash point >350 deg. C as against 140 deg. C of conventional mineral oil, with neutral return cable capable of carrying double the Phase current.

References;

1. IS:1180 (part-1)-2014 for Distribution Transformers
2. IEEEC57.12.20-2017[2] for Distribution transformers
3. IEEE Std. 519-2014. IEEE Recommended Practices and

Requirements for Harmonic Control in Electrical Power Systems.

4. IS: 17036-2018. "Distribution System Supply Voltage Quality
5. ABBs' hand book on protection, control and electrical devices.
6. Dr.K.Rajamani ,of Power Linkers, presentation on "Power Quality Overview-Practical aspects" in SIT Bhubaneswar in Feb 2020.
7. Copper Development Association –Electrical Design, A good practice guide, CDA publication 123, 1997.
8. KeithLane, PE,Lane Coburn & Associates,LLC,Woodinville,Wa-Sizing neutrals for Transformers.
9. IEEE std. 1100-1999. EM

Author
Er. K.K. Murty

- Holds a B.E.(Hons) degree in Elect. Engg. From the University of Jabalpur in the year 1968.
- He is a member of India's Society of Power Engineers (MSPE), a Fellow of Institution of Engineers, India (FIE),a Chartered Engineer (CE) and a member of CIGRE'India.
- He was a former Chief Engineer and Head of Department (Testing & Commun.) in M. P. Power Transmission Co. Ltd. Jabalpur (India).
- He was a member of the panel of Expert Professionals at the Central Power Research Institute (CPRI), Bangalore, from 2008 to 2012.
- He had worked as an Advisor (Testing) at SOUTHCO, a DISCOM in the State of Odisha,
- He was a Metering consultant to M. P. Electricity Regulatory Commission.
- He was the Course Director for the Graduate Electrical Engineering Trainees at the Training Institute of MPPTCL, Jabalpur for 2 batches (2006 to 2008)
- He has published many technical Aricles in the National and International journals and presented techical papers at various national and international conferences pertaining to the Power Transformers and other eqipments of power sector.
- He had been awarded a plaque by the Institution of Engineers(India),Kolkata, in Oct. 2015,in recognition of his eminance and contribution to the profession of Electrical Engineering at the National level.
- Enlisted in the Transfromers Technology Cosultants corner as international Transformer Cosultant from India.

–Author–
IMRAN KHAN

Imran Khan did his Graduation in Engineering from University Institute of Technology, affiliated Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal (M.P.) in 2006.

Experience

- Worked as Lecturer in Government Polytechnic, Seoni.
- Worked as an Engineer in SEC Railway (S&T) Department, Bhilai from 2006 to 2007.
- 16 years of rich experience in MP. East-zone DISCOM as Assistant Engineer/ Nodal Officer (HVDS)/ Executive Engineer.
- Presently working as Executive Engineer (Store-M.P. East-zone DISCOM).

R.N.I. No. DELENG/2011/39089
English I Monthly I Date of Publication 5th of every Month.