A case study for selection and sizing of ‘K’ rated isolation transformers in parallel redundant UPS system.

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Abstract-**Most of the high rating UPS manufacturers are manufacturing transformer-less UPS system for high efficiency and economical design. As UPS output is 3 Phase & 3 Wire, consumers generally use EB neutral to feed the single phase loads. Without isolated neutral at output, the transformer-less UPS system introduced serious power quality problems because of shared neutral with other non critical loads. Disturbances generated by other consumers pollute the neutral and the same polluted neutral is extended to critical loads. Another problem associated with transformer-less UPS system is possibility of break in neutral conductor continuity due to operation of upstream 4 pole circuit breaker. Break or loss of neutral to single phase load distribution system will result in severe voltage unbalance and over voltages leading to insulation failure. Sophisticated loads which are connected to spacecraft related hardware have very stringent requirements of clean power. This calls for providing suitable rating isolation transformer with neutral point. This paper discusses the selection of isolation transformer based on ‘K’ factor and derating of transformers and also discusses the location of isolation transformer in the UPS system.**

Key Words; ***Isolation transformer; K-rating; De-rating of transformer; Parallel redundant UPS System***

I. INTRODUCTION

Presently there is a growing interest for using transformer-less UPS system for supplying critical loads. These UPS systems uses latest developments in power and control electronics technology and offer advantages like light weight, smaller size, higher efficiency and excellent input power conditioning. The primary difference between transformer-less UPS system and transformer based UPS system is that transformer UPS system uses a transformer before the rectifier or after the inverter. The transformer is not used in transformer-less UPS system. In UPS system, transformer provides fault isolation, noise reduction, a solid neutral reference point and fault current limiting advantage. It also facilitates handling of single phase load. Single phase loads are the prominent loads supplied by UPS systems. Therefore the uses of transformers are essential in mission critical loads fed by UPS system.

The next issue is what should be the type and rating of transformer and where the transformer is to be located in UPS power distribution.

II. NON LINEAR LOADS AND DESIGN CONSIDERATION OF TRANSFORMERS

Transformers in general power transmission and distribution are designed for supplying linear loads. However transformer when used in UPS system are required to supply the non linear loads. Most of the loads supplied by UPS systems are non linear in nature. UPS in itself is a non linear load. Non linear loads draw currents which are not sinusoidal. There by producing harmonic currents which flows from load to the UPS system. The harmonic currents superimposed on the fundamental currents results in non sinusoidal waveform. Fig 1 shows the non linear nature of current waveform of the load considered for present case study.

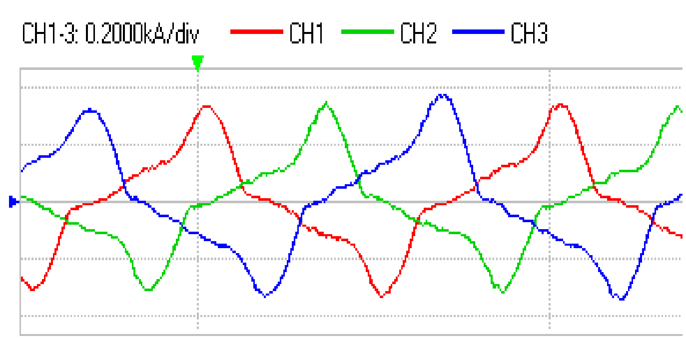

Fig.1.Non-Linear loads of UPS system

Harmonic currents cause additional heating in the transformer core due to additional eddy current losses. IEEE standard C57.110-1998 states total load losses in transformer due to presence of non linear loads as

$P_{LL}=P+P_{EC}+P_{OSL}$ Watts

Where

P_{LL} = Load loss.
P = Losses due to load current.
P_{EC} = Winding eddy current losses.
P_{OSL} = Other stray losses.

P is calculated by multiplying DC resistance of the winding with square of the load current. The eddy current losses are proportional to product square of current and square of frequency. Eddy current losses are prominently due to skin and proximity effect. Other stray losses are due to losses in structures other then winding such as clamps. It may be noted that eddy current losses are included in load losses due to presence of higher order harmonics. Normally the eddy currents losses are subject of no load losses when transformer is supplying linear load.

As evident from above discussions, the normal transformer designed for operating at power frequency will not deliver the rated power output when used for supplying non linear loads. This is due to presence of harmonics which results in over heating of transformer. The transformers if required to be used in non linear loads are required to be suitably de-rated. IEEE standard C57.110 provides methods to de-rate transformer for particular load profile.

Underwriter's laboratories (UL) have developed a rating system to indicate the capability of a transformer to handle harmonic loads. There ratings are described in underwriter's laboratories standards UL 1561 are known as transformer K-factor.

TABLE I. HARMONICS MEASUREMENTS

Harmonics Measurements			
Harmonics Order	Channel-1 R-Ph	Channel-2 Y-Ph	Channel-3 B-Ph
1	100	100	100
2	1.77	2.1	1.08
3	67.5	68.02	66.03
4	1.15	0.47	0.91
5	30.59	30.43	31.4
6	0.67	0.61	0.3
7	5.34	5.41	5.13
8	0.47	0.53	0.33
9	0.66	1.54	1.87
10	0.31	0.45	0.27
11	1.52	1.46	2.16
12	0.44	0.18	0.21
13	1.31	1.66	1.62
14	0.2	0.32	0.08
15	0.43	0.85	0.1
16	0.2	0.18	0.08
17	0.7	0.29	0.54
18	0.2	0.1	0.09
19	0.39	0.54	0.21
20	0.11	0.17	0.08
21	0.23	0.28	0.22
22	0.17	0.19	0.13
23	0.61	0.97	0.68
24	0.1	0.09	0.1
25	0.68	0.82	0.75

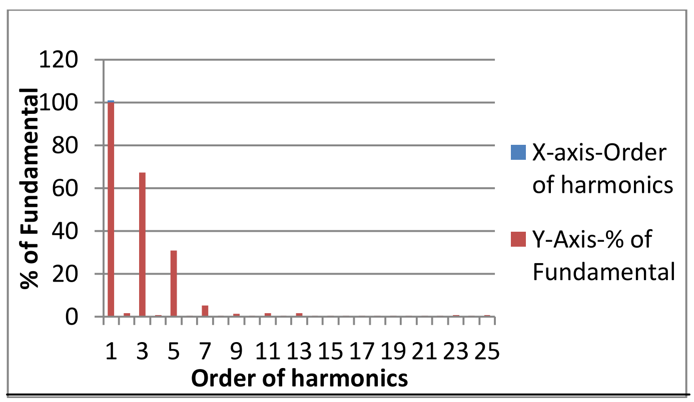

Fig.2. Harmonic Spectrum of UPS load

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III. THE CASE STUDY OF 'K' FACTOR

Referring back to the earlier discussions on the requirement of suitable isolation transformer to be used with transformer-less UPS system, the studies were conducted to know the harmonic content of the load supplied by 2 X 120 KVA UPS systems at ISAC. The measurements of harmonics are indicated in Table-I. The 'K' factor is arrived at as per the procedures available in UL 1561.

Selection of harmonics order is a problem in arriving at 'K' factor. Depending upon the instrument used for measurement of harmonics, it is possible to measure harmonics levels even up to 60^{th} order. Few instruments are capable of measuring inter harmonics also. For the same load, if the calculations are carried out up to 15^{th} order, the results will differ if the calculations are made up to 50^{th} harmonics order. Though very small current levels are associated with the higher harmonics, but when multiplied with harmonic number squared may significantly change the result. In IEEE C57.110 the 'K' factor calculations to harmonic currents are limited up to 25^{th} order.

The K factor is found from the following equation

$$\text{K-factor} = \sum_{n=1}^{n=Max} in^2\, h^2 \qquad (1)$$

Where
h =Harmonic number.
in =Fraction of total rms load current at harmonic number h.

The above equation is based on rated transformer current as per unit (PU) current.

$$\text{K-factor} = \sum_{n=1}^{n=Max} h^2 \left(\frac{In}{IR}\right)^2 \qquad (2)$$

$$= \frac{1}{I^2R} \sum_{n=1}^{n=Max} In^2 h^2 \qquad (3)$$

In equation (3) IR is the rms fundamental current at fundamental frequency and rated load conditions.

The relationship of the harmonic loss factor and the UL K-factor is given by

$$\text{K-factor} = \left(\frac{\sum_{n=1}^{n=Max} In^2}{IR^2}\right) FHL \qquad (4)$$

Equation No (1) is used for calculations of 'K' factor. The measurements of harmonics are indicated in Table-I. Table-II gives the calculations of 'K' factor. Harmonic spectrum of the recorded values are produced in Figure (2).

With the known K factor, it is possible to find the de-rating of transformer if it is intended to be used for feeding the non linear load conditions. In the present case the K factor is 5.004 which means that transformer is to be de-rated for about 87 % as shown in the figure (3).

TABLE II. CALCULATION OF 'K' FACTOR

Harmonic Order (h)	Non linear load current	In (RMS current in P.U)	In^2	in	in^2	(in)^2 X h^2
1	100.000	1.0000	1.0000	0.8031	0.6450	0.6450
2	1.6500	0.0165	0.0003	0.0133	0.0002	0.0007
3	67.1833	0.6718	0.4514	0.5396	0.2911	2.6202
4	0.8433	0.0084	0.0001	0.0068	0.0000	0.0007
5	30.8067	0.3081	0.0949	0.2474	0.0612	1.5303
6	0.5267	0.0053	0.0000	0.0042	0.0000	0.0006
7	5.2933	0.0529	0.0028	0.0425	0.0018	0.0886
8	0.4433	0.0044	0.0000	0.0036	0.0000	0.0008
9	1.3567	0.0136	0.0002	0.0109	0.0001	0.0096
10	0.3433	0.0034	0.0000	0.0028	0.0000	0.0008
11	1.7133	0.0171	0.0003	0.0138	0.0002	0.0229
12	0.2767	0.0028	0.0000	0.0022	0.0000	0.0007
13	1.5300	0.0153	0.0002	0.0123	0.0002	0.0255
14	0.2000	0.0020	0.0000	0.0016	0.0000	0.0005
15	0.4600	0.0046	0.0000	0.0037	0.0000	0.0031
16	0.1533	0.0015	0.0000	0.0012	0.0000	0.0004
17	0.5100	0.0051	0.0000	0.0041	0.0000	0.0048
18	0.1300	0.0013	0.0000	0.0010	0.0000	0.0004
19	0.3800	0.0038	0.0000	0.0031	0.0000	0.0034
20	0.1200	0.0012	0.0000	0.0010	0.0000	0.0004
21	0.2433	0.0024	0.0000	0.0020	0.0000	0.0017
22	0.1633	0.0016	0.0000	0.0013	0.0000	0.0008
23	0.7533	0.0075	0.0001	0.0061	0.0000	0.0194
24	0.0967	0.0010	0.0000	0.0008	0.0000	0.0003
25	0.7500	0.0075	0.0001	0.0060	0.0000	0.0227
						K=5.004

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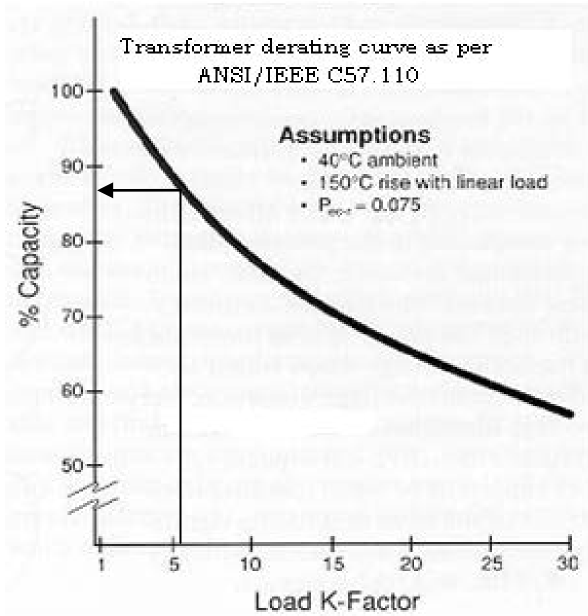

Fig.3. Transformer De-rating

IV. LOCATIONS OF ISOLATION TRANSFORMER

Transformer-less UPS system does not totally eliminate the requirements of transformer in the power distribution. However the transformer less UPS system does give flexibility of placing the transformer judiciously in UPS power distribution. It is essential to do the field survey and load survey before finalizing the location of isolation transformer in UPS power distribution.

Major options available for locating the Isolation Transformer are

1 At output side (After Inverter) of the UPS
2 At input side (Before Rectifier) of the UPS
3 At the load end

If the isolation transformer is planned at the input side of UPS Refer Fig (4), it has to compensate rectifier and inverter losses of all the modules. One advantage of providing Isolation Transformer at the input side (Rectifier side) is this configuration provides galvanic separation between the input mains and the UPS rectifier. This is preferred location if flooded batteries are used in UPS system. It provides safety for the operators handling the flooded batteries.

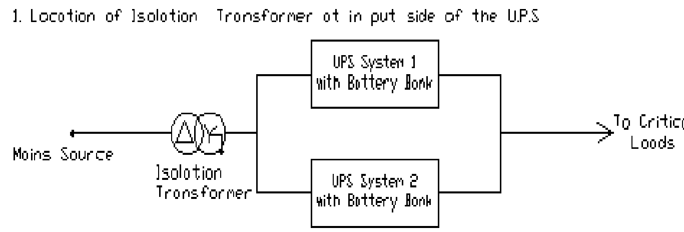

Fig.4. Isolation transformer at input of the UPS

Second possible location is output side (Inverter side) (Ref Fig (5)) of the UPS. This is most preferred location of Isolation Transformer in parallel redundant UPS systems. In parallel redundant mode, the single module of the UPS is rated for the total load supplied by parallel modules of UPS system. For example for the load is 100 KVA, two numbers of 100 KVA systems will be put in parallel to feed the load. Accordingly Isolation Transformer of 100 KVA is sufficient if the Isolation Transformer is placed at output side. Added advantage is generation of reliable neutral which is otherwise unavailable in modern transformer-less UPS system.

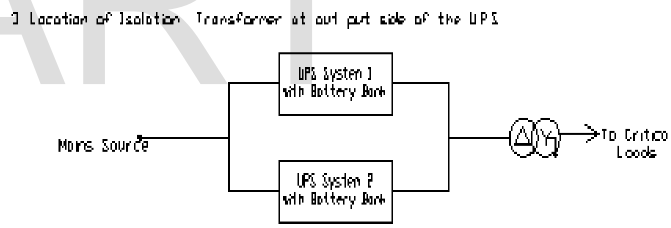

Fig.5. Location of isolation transformer at load end

Third location is placing Isolation Transformer at the load end (Ref Fig (6)). In this configuration, the multiple numbers of Isolation transformer are placed near load centres like power control centres, Distribution boards etc. Advantage of this configuration lies in elimination of laying neutral conductor from UPS output to the load centres. Disadvantage is requirement of multiple number of Isolation Transformer. Also if the load on the particular feeder increases, it will call for higher rating of Isolation Transformer. Reduced reliability due to multiple components is another disadvantage.

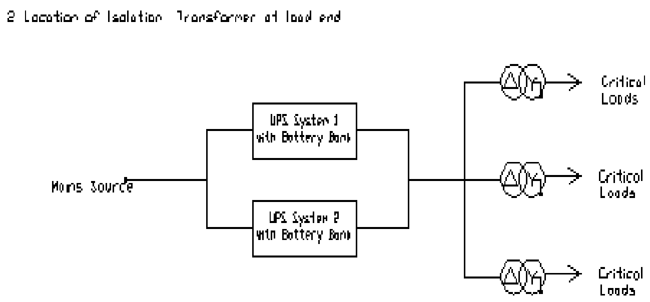

Fig.6. Location of isolation transformer at output of the UPS

V. CONCLUSIONS:

Transformer-less UPS System has been developed for efficient, flexible, lighter weight and smaller size UPS system. However isolation transformers are necessary for circuit isolation, local neutral as well as reducing the common mode noise problems. Also isolation transformers are required for providing the dedicated neutral rather than extending the EB neutral as the case with transformer-less UPS system. No manufacturer will provide isolation transformer as default with transformer-less UPS unless asked for. It is therefore required to procure isolation transformer separately.

While procuring the isolation transformer, it is required to know the harmonic contact of the load to be fed by UPS System because harmonics will generate heating in transformer. One method is to de-rate the transformer and second method is to procure suitable ‘K’ rated isolation transformer. In the present case study, the ‘K’ factor is found to be 5.004. This means that isolation transformer with ‘K’ factor of above 5 is required otherwise the transformer is to be de-rated up to 87% to avoid overheating.

Various options are available for locating the isolation transformer in UPS power distribution system. In the present case, it is found that locations isolation transformer at output side of UPS is more advantageous.

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