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Optimized Operation of Interphase Transformer for Power Converters Operating in Parallel and its Analytical Characterisation

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***Abstract*- High power converter rectifier system is used in modern day industrial and research application. Parallel Converter operation plays a vital role in large power supply system due to current sharing among them. Each converter output needs to be synchronised in a common grid. To meet high current sharing parallel operation of these converter rectifier system need utmost care due to slightest voltage variation at any instant. Such variation of voltage can be absorbed by Interphase Transformer (IPT) in various configuration mode. In this paper we have examined the synchronisation of two three phase six pulse converter rectifier system where this is put into parallel operation using IPT which reduces the of circulating current. The nodal analysis method is used to solve the circuit equations provided under different conditions.**

Keywords*—*IPT, THD, Dd0 and Dy1, Rating

I. INTRODUCTION

Multiple sources of power supply can be put in to parallel operation if their terminal voltages are equal. Otherwise a circulating current starts flowing among them which may damage the equipments. Due to the fluctuation in d.c. output voltage of the converter, the parallel operation of the converters becomes complicated. In Electro-mechanical drives, Traction and for producing plasma (the fourth state of matter) to meet high current (i:e 50 KA or more) we use parallel operation of converters. The converters connected in parallel use converter transformer to get a desired phase displacement for achieving the required number of pulses at the output. The advantages of the multipulse converter is that it has low total harmonic distortion(THD) and less ripple voltages at the output and so getting nearly perfect d.c. voltage at output. These converters are connected in parallel through IPT[1]. It absorbs difference between ripple voltages of individual converters[2] .

As described in figure.1 two six pulse converters are connected in parallel through an interphase transformer. The converters connected in parallel are fed through rectifier transformer to get *30°* phase shift, for achieving 12 number of pulses at the output[3]. The total harmonic distortion (THD) reduces with increase in the number of pulses. In this experiment thyristors are used as switches due to its high current carrying capability, robustness, longer life and working efficiency. The interphase transformer is connected between the positive and negative terminals of the converters with a series negative inductor in its secondary side.

The input to the rectifiers is given through a rectifier transformer which is of three winding and two secondary are in Y-Δ form with a phase difference of 30°.The load is connected in the output of the converter thyristors of R-L type. The absorption of voltage by the interphase transformers is solved by the circuit equations by nodal analysis method. Closed loop current control block is implemented and the system is analyzed under different conditions.IPT also used for parallel operation of choppers and also IGBT based converters. Through IPT not only two converters but also a number of converters can be connected in parallel according to this model[5].

In the given fig-1 two three phase six pulse converters are connected in parallel through a rectifier transformer. The connections of the transformer are Dd0 and Dy1 with a 30° phase difference between them. T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{21}, T_{22}, T_{23}, T_{24}, T_{25}, T_{26} are the thyristors connected for the operation. R_{load} and L_{load} are the load resistance and inductance. L_p is inductance of the interphase transformer. There is a series negative inductor connected in the secondary of the IPT as shown in the figure which plays a vital role in reducing the voltage difference. The value of that series negative inductor is $-(\frac{1}{2})L_p$ as here total two numbers of converters connected in parallel. The value of the series negative inductor is taken as such purposefully.IPT suppresses the circulating current among the converters as well as averages all the voltages of the parallel nodes.

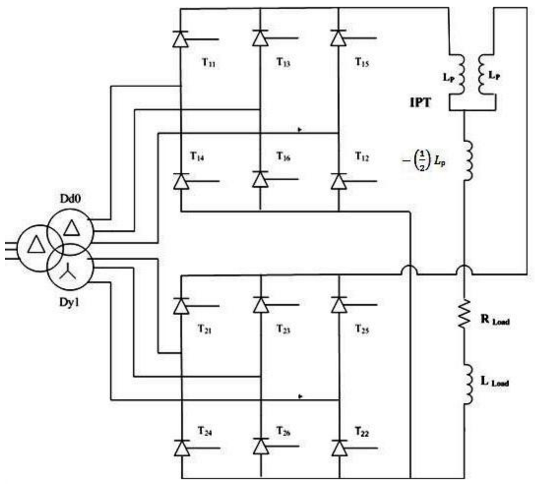

Fig.I converters connected in parallel through IPT

II. MODELLING:-

Figure-2 represents the simplified diagram of the converter operation. In this figure both converter-1 and converter-2 are connected in parallel through IPT. The positive terminals of both the converters are connected to the inductor L_p. The negative terminals of both the converters are shorted and connected to the secondary of the IPT through a negative series inductor whose value is equal to $-(1/2)L_p$. As shown in the digram I_1 is the output d.c. current of the converter-1 and I_2 is the output d.c. current of converter-2. I_1 and I_2 flows through the inductor L_p.The current flowing in it's secondary

$$I_s= I_1 +I_2 \qquad (1)$$

Also there may be small changes between I_1 and I_2 due to voltage imbalance or fluctuations of the d.c. output of the converters. If 'n' number of converters are connected in parallel the negative series inductor value would be $-(1/n)L_p$ through which the d.c. output of all the n converters would flow.

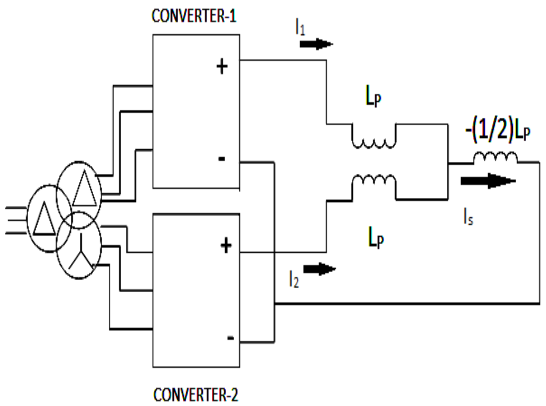

Fig.II Simplified diagram of parallel operation through IPT

III. INTERPHASE TRANSFORMER

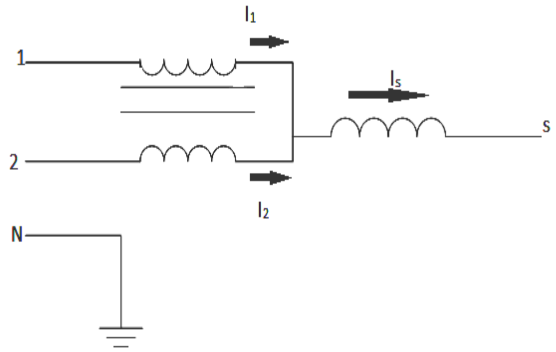

fig. III(a) Interphase Transformer

Now a days interest in parallel operation of converters with IPT has increased due to intensive use of high power rectifiers. This type connections of IPT normally suppresses the circulating current and removes the voltage difference between the terminals of the parallel connections. A two interphase transformer module with two parallel connected inductors and negative serial connected inductor is illustrated in fig-3, which helps to understand the two actions as mentioned above.

Voltage and current equations as per fig-3 (neglecting core loss, copper loss and leakage flux)

$$V_{1s}=L_p\frac{di_1}{dt} - L_p\frac{di_2}{dt} \qquad (2)$$

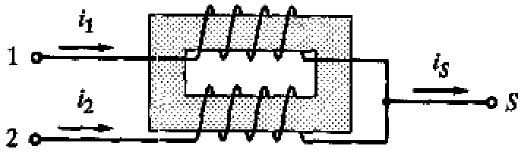

fig. III(b) IPT structure

$$V_{2s}=L_p\frac{di_2}{dt} - L_p\frac{di_1}{dt} \qquad (3)$$

Where L_P is the self inductance of the core of the leg.

From equation-1,

$$I_s= I_1 +I_2$$
$$I_1 =I_s- I_2$$
$$I_2=I_s- I_1$$

Putting this in equation (2) and (3)

$$V_{1s}=2L_p\frac{di_1}{dt} - L_p\frac{di_s}{dt}$$
$$V_{2s}=2L_p\frac{di_1}{dt} - L_p\frac{di_s}{dt}$$

Now the current is decomposed into two components i:e common mode(i_c) and differential mode (i_{d1}, i_{d2}).

$$I_c= \frac{1}{2}(i_1 + i_2)$$
$$I_{d1}=i_1-i_c$$
$$I_{d2}=i_2-i_c$$
$$V_{1s}=2L_p\frac{di_1}{dt} - L_p\frac{di_s}{dt}$$
$$= 2L_p\frac{d(i_{d1}+i_c)}{dt} - L_p\frac{d(i_1+i_2)}{dt}$$
$$= 2L_p\frac{d(i_{d1})}{dt} + 2L_p\frac{d(i_c)}{dt} - L_p\frac{d(i_1+i_2)}{dt}$$
$$= 2L_p\frac{d(i_{d1})}{dt} + 2\times\frac{1}{2}L_p\frac{d(i_1+i_2)}{dt} - L_p\frac{d(i_1+i_2)}{dt}$$

Cancelling the positive and the negative terms

$$V_{1s}=2L_p\frac{d(i_{d1})}{dt} \qquad (4- a)$$

Similarly

$$V_{1s}=2L_p\frac{di_{d2}}{dt} \qquad (4\text{- b})$$

From equation (4) it is clear that the IPT provides inductance of $2L_p$ for the differential mode current only. The figure 5-(a) and

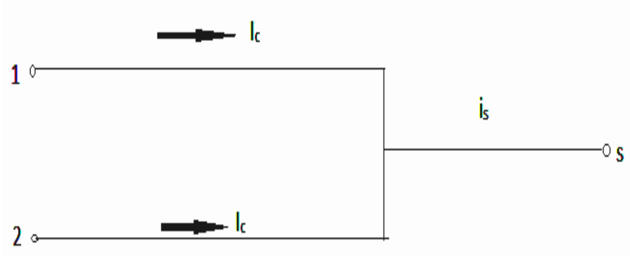

fig- IV(a) Common mode current

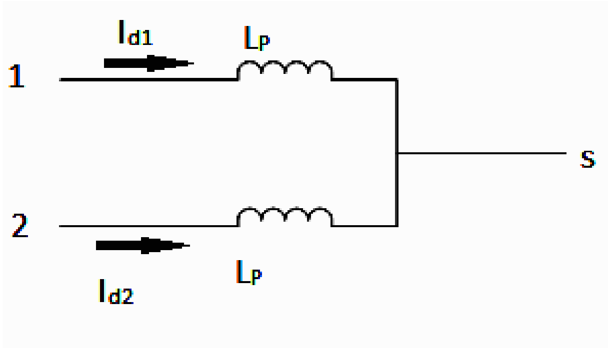

Fig. IV(b) Differential mode current

5-(b) shows the equivalent circuit of the common mode and the differential mode of current. So, IPT passes only common mode current and suppresses the differential current.

Now considering V_{s0} as the voltage of the 's' node with respect to ground.

$$V_{so}= V_{S1} + V_{10} \qquad (5)$$

$$V_{S0}= V_{S2} + V_{20} \qquad (6)$$

From equation (1) and (2)

$$V_{1s}+V_{2s}=2L_p\frac{di_1}{dt}-2L_p\frac{di_s}{dt}+2L_p\frac{dL_2}{dt}-L_p\frac{d(i_s)}{dt}$$

$$= 2L_p\frac{d(i_1+i_2)}{dt} - 2L_p\frac{d(i_s)}{dt}$$

As we know from equation (1)

$$I_s= I_1 + I_2$$

$$V_{1s}+V_{2s}= 2L_p\frac{di_s}{dt} - 2L_p\frac{di_s}{dt}$$

$$= 0$$

Adding equation (5) and (6)

$$2V_{so}=(V_{S1} + V_{S2})+(V_{10}+ V_{20})$$

$$V_{so} = \frac{1}{2}(V_{10} + V_{20}) \qquad (7)$$

From equation (7) it is clear that IPT averages the voltages of the parallel nodes.

Though there are some serious problems in structure of the core of the IPT but usage of 2-IPT for connecting two converters in parallel is usual.

IV. RATING OF INTERPHASE TRANSFORMER

Determination of rating of interphase transformer is a main part of concern as the volume and weight of the IPT depends on its rating. In figure 3-(a) the rating of i_1 winding is $V_{1s}I_1$. where V_{1s} is the rms value of voltage and I_1 is the rms value of current.

Here, $$I_1=\sqrt{I_c^2+I_{d1}^2} \qquad (8)$$

I_{d1} is pure sinusoidal with angular frequency 'ω'.

$$V_{1s} =2\omega L_p I_{d1} \qquad (9)$$

Let us assume the differential mode current is k times suppressed than the common mode current through IPT, then

$$I_{d1}=kI_c \qquad (10)$$

From equation (9)

$$V_{1s} =2\omega L p k I_c$$

From equation (8)

$$I_1= \sqrt{I_c^2+k^2I_c^2}$$

$$=I_c\sqrt{1+k^2}$$

So rating of the i_1 winding is

$$V_{1s}I_1 = 2\omega L_p I_{d1} I_c \sqrt{1+k^2}$$

putting the value of I_{d1} from equation (10)

$$V_{1s}I_1 = 2\omega L_p k\, I_c^2 \sqrt{1+k^2}$$

$$V_{1s}I_1 = k_a L_p I_c^2 \qquad (11)$$

Where $K_a=2\omega k\sqrt{1+k^2}$

So the total rating of the two IPTs is

$$V_{1s}I_1 + V_{2s}I_2 = 2k_a L_p I_c^2 \qquad (12)$$

V. EXEMPLARY RESULT

The shown voltage profile is an exemplary result by taking a small amount of voltage at the input side and connecting an equivalent of interphase transformer at the output. The circulating current effect has been reduced upto a greater extent.

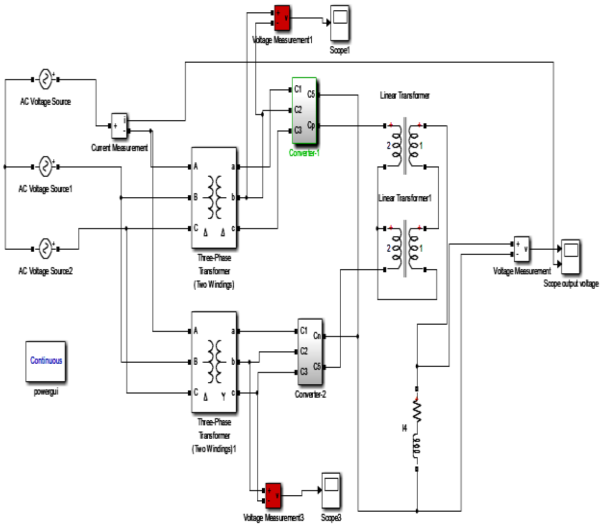

Fig.V MATLAB model of the operation

The fig.VI result is taken by considering the same structure as described above and taking a RL load of very less magnitude for an example for observing the operation of IPT.

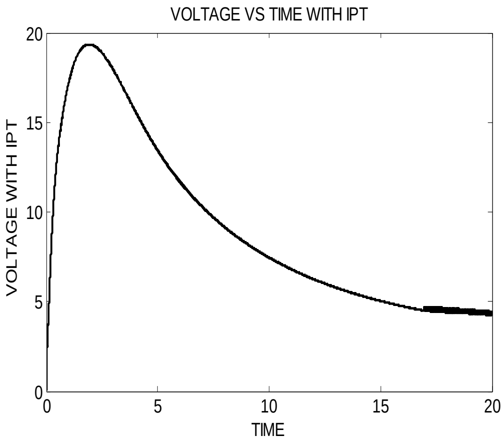

FIG. VI Simulation result

VI.CONCLUSION

The presented method facilitates the choice of an arrangement of converters in order to reduce the ratings of the thyristor, size of the thyristor through parallel operation. Also it is a little more cost effective but very helpful for long term operation also. The result of a simple example shows that, even if there are only two converters working in parallel, optimized operating strategies are not trivial. This method of connecting two or more number of converters in parallel proposes a brief idea of parallel connection, working of the IPT, rating of the IPT and still also there are other ways to build the better result. The analytical characterization of the interphase transformer is briefly given in this paper for it's better use purpose.

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