Novel Testing Kit for Automatic Power Factor Correction (APFC) Relay

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***Abstract*—**This paper is based on manufacturing of novel testing kit for APFC relay. In novel testing kit the currents and voltages of only two phases were used to test the relay. In existing testing kits, due to application of inductive load the losses during testing were very high. This problem was overcome in novel testing kit, which tested the relay with purely resistive load.

Keywords—*APFC; Novel; Existing testing kit; Resistive load; Voltage coil; Current coil; Testing; Phase Angle.*

I. INTRODUCTION

Electricity consumption is increasing day by day. The charges applied by the supply authorities for electricity consumption are also increasing which causes effective increase in per month energy bill. So now every consumer whether he is industrial residential or commercial is mainly focusing on reducing the electricity bill. The main factor, which effectively increases the monthly energy bill of industrial and commercial consumers, is the reactive power drawn by the inductive loads from the supply system. This condition is also called as low power factor of loads. Hence main focus of consumers is on power factor improvement. Due to this there is an effective increase in demand of APFC relay and every day numbers of new manufacturers of APFC relay are entering into the market so what if a special testing kit of APFC relay is introduced in the market at very low cost for such small scale manufacturers.

When the manufacturer manufactures relay or any protective and controlling system then it should be tested for its precision, stable and reliable operation. For this purpose various testing kits are available in the market. The novel testing kit proposed in this paper is mainly focusing on testing of APFC relay. Also it can be use as a part of existing universal testing kit to perform phase angle test on different types of relay.

APFC relay is mainly focused because almost all the industrial and commercial consumers to reduce the monthly electricity bill by automatically controlling the power factor and maintaining it around unity use it. If power factor is maintained at its ideal value i.e. unity then reactive power consumed by the load will be zero. Each capacitor of a capacitor bank, which is generally used for power factor improvement, is connected to the APFC relay. APFC relay measures the load power factor compares it with target power factor and switches ON the capacitors of capacitor bank to correct the power factor. The target power factor is the value of power factor set by the consumer or manufacturer at which he wants to maintain the load power factor. It automatically switches ON and off the capacitor to avoid over compensation.

If APFC relay provided by the manufacturer is faulty it may not switch ON the capacitor to correct the power factor or it may overcompensate by switching ON the capacitors more than required.

If novel testing kit is compared with the existing testing kits that are available in the market then it can be noticed that in existing testing kits purely inductive load is used to provide the phase angle for relay testing whereas in novel testing kit purely resistive load is used to provide the phase angle for relay testing which has its own advantages.

When APFC relay is connected in actual circuit operation for power factor correction or when APFC relay is tested on existing kits, the current of that phase for which power factor is to be controlled is connected to the current coil of the relay and line voltage of other two phases is connected to the voltage coil of the relay. But in NOVEL testing kit the current and voltage of only two phases are used to test the relay. Also in existing testing kits, which tests the relay by connecting it to the inductive load the losses during testing is the biggest problem arise due to continuous operation of purely inductive load. This problem is effectively overcome in novel testing kit, which tests the relay with purely resistive load.

Working principle, construction, working details, theoretical aspects, practical aspects etc. is explained in this paper

II. RELAY TESTING CIRCUIT COMPONENTS

A. Summation Current Transformer (CT)

Working of novel kit was completely based on very basic theoretical aspect i.e. the reversal of current $I_{B.}$

Now the main question was “How to reverse current IB !!”

This was done by summation current transformer which was used normally to add currents of two circuits and apply it to the circuit connected at the output.

In normal connection the windings of summation CT were connected as shown in figure A_1.

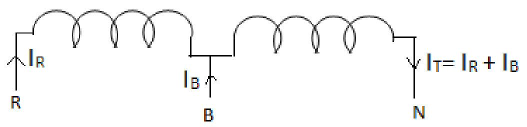

Fig. (A_1) Normal connections of Summation CT primary

Figure shows the primary winding connection of summation CT. From the figure it was noticed that the current I_R & current I_B entered the winding at points R & B respectively. Both the currents got added and the respective current appeared at the secondary winding of summation CT. In novel testing kit simply the connection of phase B were reversed to reverse the current I_B. The detailed connections of summation CT primary winding which was used in novel testing kit were as given in figure A_2

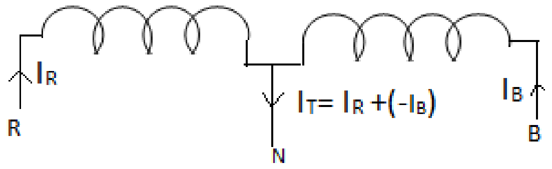

Fig. (A_2) Connections of Summation CT in novel testing kit

Hence direction of current I_B is reversed as seen in figure (b) and reversed current I_B is denoted by $-I_B$. This condition can be more clearly understood from the phasor diagram shown in figure A_3.

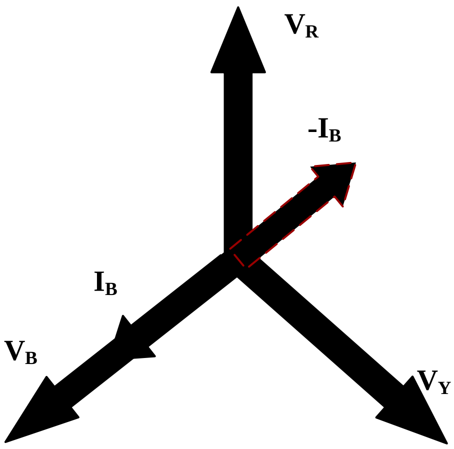

Fig.(A_3) Phasor diagram with reversed current $-I_B$

B. Salzer based plug in type relay cum contactor

Fig (B_1) Salzer make plug in type relay

The snap shown in figure B_1 is a Salzer based plug in type relay which was used to add the capacitors in the circuit to improve the power factor whenever the power factor sensed by APFC relay was less than its target value.

This was simply an 11 pin plug in relay with 1 coil energizing 3 NO contacts and 3 NC contacts. When coil was energized the NO contacts got closed and NC contacts got opened.

The internal control circuit arrangement is shown in figure (B_2).

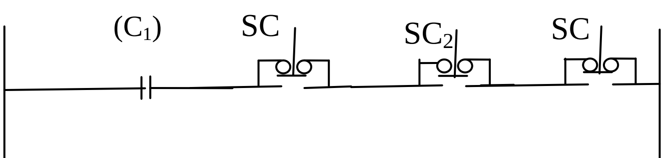

Fig. (B_2) Internal control circuit of plug in relay

- C_1:- Energizing coil
- SC:- Changeover Contacts

Energizing coil (C1) was connected to its three changeover contacts (SC1, SC2, SC3). When coil was energized with 230 volts AC supply, it changed the state of all its auxiliary contacts.

In novel testing kit, NO contacts of these relays were connected to the capacitor. As all the contacts closed at the same time after the coil was energized, for each capacitor separate plug in relay was used. Otherwise if three capacitors of the capacitor bank are connected to the three NO contacts of the same relay then whenever relay sent signal to add one capacitor then unnecessarily all three capacitor were getting added which leaded to overcompensation.

Therefore, to test six stage APFC relay 6 plug in type relays were required to be present in the novel testing kit. The one terminal coil of each plug in type relay was connected to each stage of relay and other terminals of all the coils were connected to the neutral.

C. Resistors

As stated earlier, the novel testing kit tests the relay on purely resistive load. Hence, five resistors of 500 ohms 20 Watts each were connected in series with transformer primary. This resistive circuit was supplied from phase B. A toggle switch was connected in parallel with each resistor, which made variation of load possible.

D. Two Winding Transformer

A two winding transformer of 240/12 volts 60 VA was used in novel testing kit to increase the current level of the resistive load circuit up to 5 amperes. Since in 240/12 volts step down transformer the voltage was reduced by factor 1/20 and current was multiplied by 20.

E. Capacitors

To test the 6 stage APFC relay 6 capacitors were required one for each stage. Three 10 µF, two 8 µF and one 6 µF capacitors were used. The respective calculation made to obtain the required value capacitors are shown later in calculation section.

III. WORKING

Working of novel testing kit was understood easily when it was compared with working of existing testing kit. The comparison is given below.

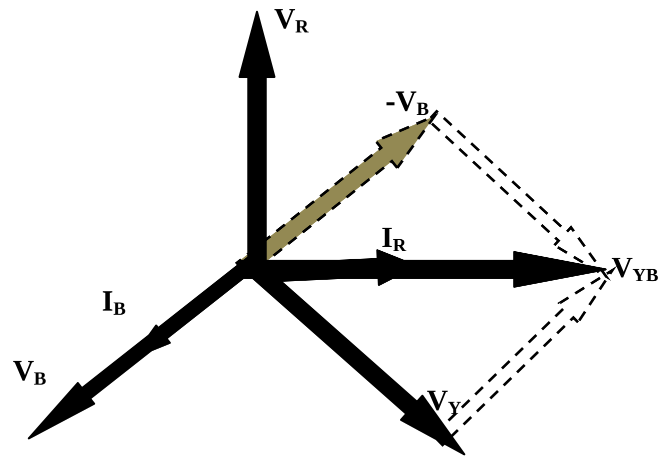

Fig. (4.1) phasor diagram showing working of existing testing kit

Firstly lets understand the testing of the relay on existing testing kits, if relay is to be tested on phase R, then the line voltage V_{YB} is applied across the voltage coil of the relay. Moreover, the current of phase R is applied across current coil of the relay. The phasor diagram for this condition can be drawn as shown in figure 4.1.

The voltage V_R and current I_R was having 90^0 phase shift between them due to purely inductive load.

Hence $Ø=90^0$------(i)

And power factor cos (Ø)= 0 ------(ii)

The voltage V_{YB} and current I_R were having 0^0 phase shift between them as seen from the phasor diagram in fig. 4.1

Hence $\Theta=0^0$-----(iii)

Relay internal connections were made to increase angle ϴ which consequently decrease angle Ø. For ex.: if relay under test sends signal to the contactor to switch ON the capacitor, causing increase in angle ϴ from 0^0 to 30^0 then angle Ø will decrease from 90^0 to 60^0. Which increases the power factor from cos(Ø)=0 to cos(Ø)= 0.5

Moving over to the working of novel testing kit in which, as stated earlier only two phases were used and no third phase was involved. Line voltage V_{YB} was applied across the voltage coil of the relay and current I_B which as stated earlier was reversed by summation CT was apllied to the current coil of the relay. This was easily understood from the phasor diagram shown in figure 4.2.

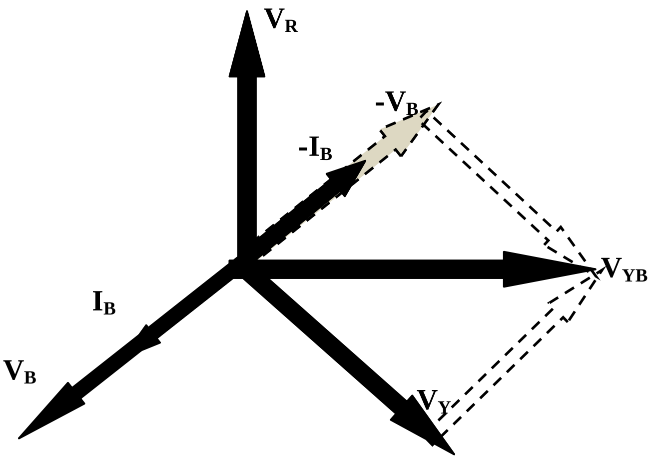

Fig. (4.2) phasor diagram showing working of novel testing kit

The voltage V_R and current $-I_B$ were having 60^0 phase shift between them.

Hence $Ø=90^0$------(iv)

And power factor sensed by the relay

cos (Ø)= 0.5 ------(v)

The voltage V_{YB} and current $-I_B$ were having 30^0 phase shift between them as seen from the phasor diagram.

Hence $\Theta=30^0$-----(iii)

Here no I_R was involved and current $-I_B$ was applied to the current coil of the relay. Hence current $-I_B$ was sensed as I_R and sent signal to switch on the capacitors increased the angle ϴ and consequently the angle Ø decreased.

IV. RESULTS & DISCUSSIONS

1. Let's calculate the total resistance connected in the circuit. Since the resistances are connected in series, the total resistance is given by:

   $R_T = R_L+R_1+R_2+R_3+R_4+R_5$

   Where

   R_T = Total resistance in ohms

   $R_1 =R_2=R_3=R_4=R_5$= 500 Ohms
   R_L = Resistance of lamp given by the equation

   $$R_L = \frac{voltage\ across\ lamp}{current\ through\ lamp} = \frac{240}{IL}$$

   Current through 60 W lamp when connected across 240 Volts AC supply is given by,

   $I_L = \frac{60}{240}$= 0.25 Amperes

   Therefore, $R_L = \frac{240}{0.25} = 960\ \Omega$

2. 240/12 V, 60VA transformer is used for current input to APFC relay. Since by using this transformer the voltage level is reduced by 20 times the current level is increased by 20 times. Hence the current input to the relay under test at full load is calculated as follows.

   Hence current input to APFC relay under test =

   0.25×20= 5 A

3. 10,8,& 6 µF condensers are used as compensating capacitors in the test circuit. Capacitor current per microfarads is given by:

   I_c per µF = $2\pi fC\times V = 2\pi\times 50\times 1\times 10^{-6}\times 240 = 0.076$ Amp

4. Power factor compensation provide by any X µF capacitor in terms of 3 phase KVA can be obtained by formula,

   $3 \times kV \times X \times I_C$ per µF × CT ratio

5. Calculations in the table 3.1 shown below are for theoretical assessment of the condensers to be connected through step outputs of APFC relay under test and corresponding values of compensated power factor for different values of loads.

   The calculations are made for six stages of APFC relay under test:

Table. (3.1) calculations for condensers to be connected

Load SW ON	Resistance in ohms (R)	Load current in amp $=\frac{240}{R}$	Current to relay $I_{load}\times 20$	Active component of current= $I_{relay}\times 0.5$	Reactive component of current= $I_{relay}\times 0.866$	Capacitors to be added (µF)	Reactive component supplied by the capacitor $X\times 0.0754$	Uncompensated current left (6-8)	tanØ= $\frac{9}{5}$	cosØ= $\frac{1}{\sqrt{1+\tan^2 Ø}}$
1	2	3	4	5	6	7	8	9	10	11
1 to 6	960+0	0.25	5	2.5	4.33	3×10+2×8+6 =52	3.952	0.378	0.1512	0.99
1 to 5	960+500	0.1644	3.288	1.644	2.847	3×10+6=36	2.736	0.111	0.0675	0.99
1 to 4	960+1000	0.1224	2.448	1.224	2.12	10+10+8=28	2.128	0.01	0.0082	0.99
1 to 3	960+1500	0.0975	1.952	0.976	1.69	8+8+6=22	1.672	0.018	0.0184	0.99
1 to 2	960+2000	0.0811	1.622	0.811	1.404	10+8=18	1.368	0.036	0.0444	0.99
1	960+2500	0.0693	1.388	0.694	1.202	8+6=14	1.064	0.138	0.2	0.98

V. ADVANTAGES & LIMITATIONS

When novel testing kit is compared with existing testing kit following advantages were noticed:

1. As purely resistive load was used instead of inductive load, losses during testing are reduced.
2. To manufacture existing testing kits inductors of required inductance or reactance are needs to be designed

separately whereas resistors which were used in the novel testing kit were directly available in the market

3. Separate design of inductors adds on to the cost of testing kit, which didn't happen in novel testing kit Absence of inductors made calculation easier, which was not the case of existing testing kit.
4. As initial power factor was unity due to resistive load, the power required was less.
5. Reactive power drawn by the line was negligible due to resistive load.

Novel testing kit when compared with existing testing kit the only limitation was noticed which is given below.

Existing testing kits tests the relay for various values of power factor ranging from cos (Ø)= 0 to cos (Ø)= 1. i.e. the angle between voltage and current of R-phase varies in the range of 0^0 to 90^0. Whereas in novel testing kit power factor variation is limited in the range cos(Ø)=0.5 to cos (Ø)= 1. i.e. the angle between R-phase voltage and reversed current -I_B varies in the range of 0^0 to 60^0.

CONCLUSION

Novel testing kit can replace existing testing kits to test APFC relay. It can be used as a part of universal testing kit to perform phase angle test on all types of relays. It can be made available at a very low cost to the small scale manufacturers who manufactures only APFC relay. It is too affordable that even the consumers of APFC relay can buy it along with the relay to test the relay periodically.

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