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A novel technique for voltage control with a view to reducing power consumption in single phase domestic loads

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Abstract

Loads connected in parallel with the supply (the supply being normally A.C) are normally controlled using series rheostats etc. resulting in loss of energy. The loads normally are light and fan loads having power ratings ≤100W. For controlling power fed to these loads the supply can be of mixed type (discussed later to be both A.C and D.C). D.C supply which can be easily obtained using rectifiers can be used to drive fans. The A.C input to the rectifier can be passed through a suitable load which was previously connected in parallel with the supply. Generally lighting and charging loads are highly suitable for this purpose. Another perspective of this circuit is the possibility of synthesizing hydrogen (an alternate fuel) and oxygen. When properly designed light, motor and charging load may be simultaneously applied. Thus the power previously being wasted in the power controlling device is now being used up by separate devices increasing efficiency.

Keywords: D.C, capacitor, power, load, power density

Introduction

Domestic supply in India is 230V-50Hz A.C. The light and fan loads are designed to operate at this voltage and frequency. These days triac based electronic fan regulators are used for speed control of fans and electronic ballasts are used to power fluorescent tubes (referred as 'tube light' from hereon). Each and every load is connected in parallel. The system of *'series lighting'* is not used i.e. none of the loads are connected in series. In this context three points are worth mentioning

a. Ceiling fans are not always required to operate at their maximum speed (the very reason for which triacs are used).
b. Tube lights equipped with electronic ballasts can operate at a much lower voltage than the rated one i.e. 230V. Also often the full lumen output is not required.
c. Cell phone chargers can charge batteries at low voltages compared with 230V and absorb power in the range of ≤5W.

Keeping in view the above points the concept of *'series-parallel'* connection may be evolved. The essence of this design is *'voltage division rule'*. The principle is the same as the one used in a resistance type fan regulator i.e. a resistance in series may be used to drop a considerable amount of voltage across it thereby supplying a reduced voltage across the load with consequent reduction in speed of the fan motor. This proves to be quite simple and effective except for power loss in the series resistor. A variable series inductance with a low ohmic resistance would perhaps a better alternative. But again these would be very expensive at first cost as well as bulky. A series capacitor on the other hand would lower the voltage to such an extent that the original load may not operate at all.

The solution to these problems lies in the use of two techniques in combination

a. Use of mixed supply to drive the loads i.e. partly A.C and partly D.C instead of purely A.C.
b. Use of series-parallel operation of loads instead of only parallel operation.

The details have been expounded in the subsequent sections.

Materials

1. 1N4007 diodes
2. Electronic fan regulator (based on triac)
3. Fluorescent tube 40W
4. Electronic ballast
5. Transformers having 230V primary and secondaries 9V/.5A, 12V/3A, 12-0-12V/1A
6. 2.5µF capacitors
7. D.C fan
8. LED bulb 5W
9. GLS lamps 15W, 40W, 60W, 100W, 200W
10. Multimeter and voltmeters.
11. Choke coil

Experimental

A bridge rectifier using four diodes converts A.C to D.C. This pulsating D.C can be used to power GLS lamp, D.C fan and fluorescent tube (equipped with electronic ballast) without need for any additional filtering circuit. Again a GLS lamp and a fluorescent tube can work on A.C as well as D.C. So there may be two control options; one from the A.C side whiles the other from the D.C side. Keeping these in mind a series of experiments was performed.

Experiment 1: A simple experiment was tried at first. A bridge rectifier was used to power a D.C fan. The LV side of a 230-12V, 3A transformer was connected in series with the A.C side. The aim was to drop a few volts on the LV side so as to induce voltage on the HV side. The circuit was switched ON and the voltage drop on the LV side was 5.5V and it produced a no load voltage of 100V on the HV side. But apparently this was of low *'power density'*. So when this was fed to a 40W GLS bulb, the bulb would not light. The D.C voltage across the fan was 205V. The fan was replaced with a 100W GLS bulb the remaining circuit remaining same. The bulb lit up. A 25W GLS bulb was connected with the LV side of the transformer. No significant change could be observed. When the same load was connected across the HV an increase in output of the 100W GLS lamp was observed.

When a 2.5µF capacitor was used instead of the transformer the A.C voltage across the capacitor was 190V while the D.C voltage across the fan was 90V.

A series choke on the A.C side absorbs 75V while 140V D.C appears at the rectifier output. On connecting a tube light to the D.C side it lights up but a continuous humming noise is heard from the choke which gets eliminated by putting a 2.5µF capacitor in parallel with the choke.

A fluorescent tube in series with the A.C side consumes 145V and glows steadily giving 100V D.C across the fan. The fan rotates at a reduced speed.

Experiment 2: The LV side of a 230-12V transformer is connected in series with the input of a bridge rectifier and a fan was connected to the D.C side. In addition a 2.5µF capacitor is connected across the fan. Just as in the case of the previous experiment the fan started rotating. Now a 5W LED was connected at the HV side. The LED started flickering and careful observation showed that the frequency of the flickers was synchronous with the speed of the fan. Clearly the LED was receiving power in *'pulses'*. To make the power at the HV side continuous the load was slowly increased to 200W. This was done by connecting a tube light and a 100W GLS lamp in parallel with the D.C side. Now the LED gave a steady lumen output. The same was repeated using a 9W LED. This also gave its normal output. But when both LED's were connected in parallel, the 9W LED refused to light up. However a 15W GLS lamp would light up normally when connected to the HV side. When the HV is on open circuit a continuous humming noise is heard from the transformer which disappears once the load is connected.

Experiment 3:

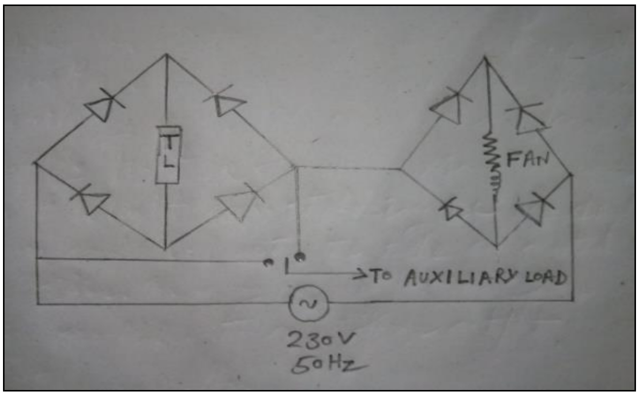

Fig 1

Two bridge rectifiers were connected in series across an A.C supply. The output of the first (Rectifier A) was given to a tube light while that of the other (Rectifier B) was given to a D.C fan. A 2.5µF capacitor was connected in parallel with the fan. The D.C voltages across the fan and the tube light were 45V and 155V respectively. A 5W LED was connected across the A.C side of Rectifier A. The A.C voltage across this was 160V. The inclusion of the LED lamp also increased the speed of the D.C fan. This implied more voltage across the fan. But when the same lamp was connected across the A.C side of Rectifier B the fan stopped and the bulb lit up with its normal glow.

As observed from the previous experiment control of the speed of the fan using a series tube light leaves two options; one wherein the tube light is operated from A.C and the fan is operated on D.C, the other being the possibility when both the loads are operated on D.C which necessitates the use of two bridge rectifiers instead of one. The former leads to a bit higher fan speed as compared with the later.

Experiment 4:

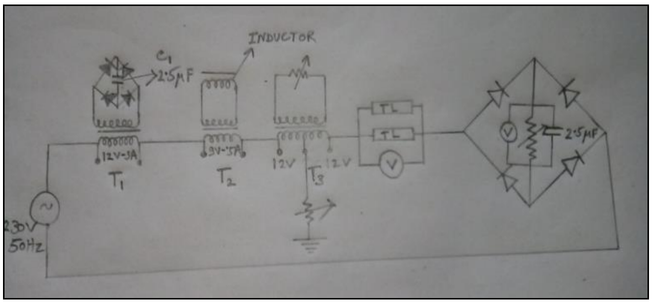

Fig 2

The LV sides of three transformers 12V-3A (T_1), 9V-.5A (T_2), and 12-0-12V-1A (T_3) were connected in series with a tube light and this entire combination was connected in series with a bridge rectifier. A GLS lamp in parallel with a 2.5µF capacitor was connected at the D.C side. Two voltmeters were used; one across the tube light and the other across the D.C output of the rectifier. The outputs (HV sides) of the transformers were connected in the following manner T_1 to a bridge rectifier with a 2.5µF capacitor (C_1) at the D.C side, T_2 to a relay coil, T_3 to a 15W GLS lamp respectively. When the load on the main circuit was 200W a D.C voltage of 1000V was obtained at the capacitor terminals C_1. The voltage across this capacitor depends on the value of the load on the main circuit. Further increase in load results in still higher capacitor voltage. On connecting the capacitor terminals to a solution of sodium chloride, the voltage drops to 12V D.C and the solution gets electrolyzed. In this way hydrogen may be produced. The glow of the 15W lamp is faint. The tube light consumes about 80V when the load on the D.C side is 100W. This increase gradually as the load on the D.C terminals is increased resulting in consequent decrease in its own voltage. A conventional tube light (one with a choke and starter arrangement) was connected in parallel with the original tube light to study the behavior of the circuit more closely. It was seen that when the load on the D.C side became 60W the tube light started flickering i.e. striking voltage had been reached. When increased to 100W the tube lit up. A low value of load about 25W could be supplied from the 0V point of T_3 and the earth pin of the wall socket. Doing this also increases the D.C voltage across the load. But this can be some only if the live wire is close to the transformer. If the neutral is close, this is not the case. The connection of the lamp also increases the voltage across the tube light and a conventional tube light is easy to light up with this connection. But since a conventional tube light requires more voltage to light up, it requires higher loads on the D.C side.

Observations

A series transformer of suitable rating allows slight reduction in the terminal voltage on the D.C side when connected in series with a bridge rectifier. This configuration also facilates supply of an auxiliary load from the HV side such as a cell phone charger. A series inductor (choke coil) much like the LV of a transformer also provides reduction in D.C terminal voltage. But the choke having only one terminal is incapable of supplying an auxiliary load unlike a transformer. The implication is that if a load is connected at the inductor terminals, overall impedance is reduced with consequent decrease in voltage reduction capability. A transformer is a better alternative because its HV and LV sides are inductively coupled and no electrical connection exists between the two.

As for a series capacitor the method and characteristics of such a circuit have already been studied[1].

A series combination of two rectifiers is a very efficient method of voltage reduction while providing power for an auxiliary load. This method can be used to supply light, fan and an auxiliary load simultaneously. More over careful observation reveals that a tube light supplied from the D.C source as depicted earlier works better than when connected directly to the A.C line (i.e. in case of a single rectifier and tube light). This is so because a tube light connected in series may show the tendency to fluctuate at the frequency of the fan's rotation. A tube supplied using D.C (i.e. in case of two series rectifiers) has no such problems. In every case a capacitor connected across the D.C terminals increases the output voltage slightly (about 5V).

The technique described in experiment no.4 provides efficient reduction of terminal voltage and has the capability of supplying a number of auxiliary loads at the same time. But the design requires careful selection of the loads and systematic switching.

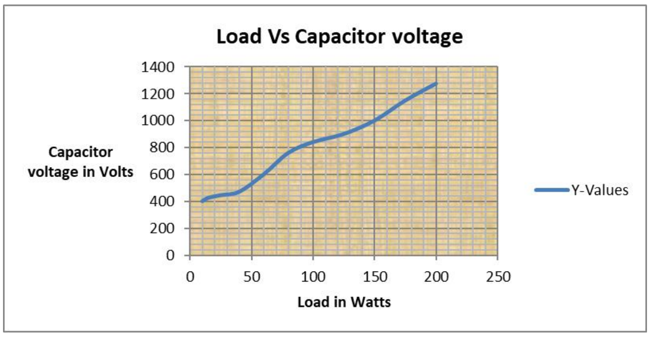

Fig 1

Results and Discussions

The important results have been summarized below:

1. Series transformer, series inductor and series loads are effective methods of controlling power fed to a load
2. The control is very effective when the loads are supplied using A.C and D.C.
3. A series transformer provides for voltage reduction on the D.C side, the amount of reduction depending on the rating of the transformer. The HV terminal has *low power density* and hence can supply light loads ≤5W. However electrolysis is possible after rectification of the voltage obtained from the HV side. The HV side has poor voltage regulation and capacitors are unable to boost it.
4. Two rectifiers connected in series provide high efficiency control of voltage for both light and fan loads. In this case also provision exists for supply of auxiliary loads such as LED's and cell phone chargers.

A simple example will expound the entire results

Let us consider a small room where only light and fan load will be needed. We shall equip this room with a single tube light and a fan. The supply to this room is 230V-50Hz A.C. To wire it up we will use eight 1N4007 diodes to design two rectifiers which will be connected in series with each other and supplied from the 230V A.C source. The tube light shall be supplied from one rectifier while the fan from the other. A cell phone may be charged from the A.C side of either rectifier. Similarly a LED up to 10W may be lit from the same A.C side. If higher speed of the fan is required simply we can add up the voltages of the two rectifiers by taking the negative supply of the fan from one rectifier and the positive supply from the other. This will impress full voltage upon the fan thereby increasing its speed. The remaining loads may remain connected as it is.

Any of these techniques singly or in combination can be utilized for supplying loads ≤200W for domestic applications. The methods are efficient and save up to 20% power as compared with ordinary control techniques.

Conclusion

A *'heterogeneous'* supply based A.C mains and subsequent conversion of A.C to D.C can supply light and fan loads simultaneously connected in series. This results in efficient speed control of the fan motor without requiring additional control equipment. Low wattage auxiliary loads may also be supplied using this method. In these method domestic utilities having loads ≤200W may be easily supplied while reducing power consumption.

Acknowledgements

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