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An experimental research on the feasibility of shaft voltage as a potential and economic low power source

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Abstract

Electric motors of low wattage rating while in operation have an e.m.f between the rotating shaft and the ground pin of the wall socket. The value of this voltage, better known as '*shaft voltage*' ranges from a few mV to as large as 100V depending on a variety of factors. In A.C motors the shaft voltage is alternating in nature while in D.C motors this is either negative or positive relative to ground though A.C components of the order of mV are frequently present. Shaft voltages of high magnitudes are considered detrimental and techniques are adopted to minimize it. A voltage of the order 5V is not infrequent. Instead of minimizing, it may be used to feed loads not requiring high power. Indeed this is the case and the load current in no way affects the current drawn by the motor whether in magnitude or waveform. In this paper nature of '*shaft voltage*' and techniques for harnessing it has been elaborated.

Keywords: shaft voltage, regulation, polarity, leakage, coupling

Introduction

Electric motors are not uncommon in our daily lives as they perform a variety of tasks. Of these the commonest application is a fan. Blades are attached to the metallic shaft which rotates once the motor is energized thereby making the blades rotate due to mechanical coupling between the blade and the shaft. The rotating shaft is visible in table fans and D.C fans. All these fans have an emf what we call 'shaft voltage'. Now what is this 'shaft voltage'? A bit insight in to the matter is necessary before proceeding further.

Experimentally speaking, when on terminal of a sensitive voltmeter is connected to the rotating shaft and the other terminal is connected to the ground pin, the voltmeter shows deflection, indicating a voltage between the rotating shaft and the ground. This is known as *'shaft voltage'*. There are various causes for the inducement [1] of shaft voltage among which number the following:

1. Leakage current from the motor windings— this may be due to deterioration of the winding insulation with aging of the motor causing leakage which energizes the shaft.
2. Inductive coupling of the shaft with the windings— the windings being inductive in nature transformer emf is induced in the shaft which acts as a single turn secondary.
3. Capacitive coupling of the shaft with the windings— since there are conductors along with insulation which acts as dielectric, capacitive effects are sure to exist due to the formation of many '*fictitious*' parallel plate capacitors.
4. Non-symmetrical magnetic fields of the motor itself— non-symmetry may arise due to mechanical distortion of the windings and the core as the motor ages, the poles may not align themselves in a way they ought to be aligned to ensure proper symmetry.
5. External causes including coupling with other machines and electrostatic charging which might be due to rubber belts etc.

Another possible cause could be magnetic leakage which induces emf as per $e=-N\frac{d\phi}{dt}$. But again this is purely alternating in nature. All these properties either singly or in combination cause the inducement of 'shaft voltage'. Generally every rotor bears a certain degree of capacitive coupling to the electrical windings which causes the appearance of shaft voltage.

On connecting a line tester with the rotating shaft, the tester glows providing direct circumstantial evidence to the existence of a voltage at the shaft. This is a simple and purely experimental observation. The magnitude of shaft voltage depends mainly on two factors *viz*.:-

1. The degree of inductive/capacitive (as the case may be) of the electrical windings with the shaft.
2. The condition of the insulation; old motors may possess worn out insulation causing the appearance of higher voltage at the shaft.

However high the shaft voltage might be, the means of harnessing the same largely depends on the amount of power that it is capable of supplying. Sometimes the voltage is quite high when measured under no load conditions but on the application of a load as low as 5W, the voltage instantly drops below 1V thereby preventing its further use.

Experimental

The first task was to detect the presence of voltage at the rotating shaft. For this purpose the blades of a table fan were dismantled and the shaft was made to rotate without mechanical load by impressing rated voltage of 230V. A line tester was 'touched' with the rotating shaft which glowed. The same process was repeated with a forty year old D.C fan. Apparently higher voltage was present at the shaft of the D.C fan indicated by the brighter glow of the line tester. The voltage being detected, the second thing was to determine its nature. For this a highly sensitive as well as precise analog multimeter was taken. The voltage at the shaft of the table fan was A.C while that in case of the D.C fan was its opposite. Both these measurements were taken relative to ground at zero potential.

A series of observations was made chronologically on the table fan *viz*.:

i) The no load voltage measured between the shaft and the ground was 3V.
ii) The voltage was rectified using a bridge rectifier and the output D.C voltage was approx. 3V on no load. This was fed to NaCl solution. Bubbles were observed at the cathode and the terminal voltage was found to be 1.2V. Increasing the strength of NaCl solution i.e. increasing its conductivity caused further decrease in terminal voltage. Addition of a capacitor of 4700µF worsened the condition.
iii) The '*polarity*' of the supply was reversed i.e. the positions of the live and neutral wire were interchanged. The voltage (both under no load and loaded conditions) increased. Evidently the voltage was dependent on the polarity of the supply.
iv) Operation of the fan regulator with a view to reducing the speed caused reduction in shaft voltage in both cases.
v) Ordinary transformers were unable to step up the voltage. Though on no load a voltage of ≈20V was encountered at the HV terminals, it instantly dropped below 1V even on the application of a very small load. A capacitor behaved in a manner identical to the earlier case i.e. it caused further decrease in terminal voltage.
vi) On rectification the voltage was able to light up LED's rated 3V D.C. It was possible only due to the extreme low value of current drawn by a LED.

As the voltage under all circumstances was below 10V, there was no question of testing loads such as incandescent lamps or fluorescent lamps.

Now experiments were conducted on the rotating shaft of the D.C fan. The no load voltage was 100V w.r.t ground (at zero potential). Though its magnitude remained independent of the polarity of the D.C supply, its sign was polarity dependent. A 100W incandescent lamp connected between the shaft and the ground glowed brightly with a lot of flickering. Constant sparking was observed at the contact point of the shaft and the '*collecting rod*' (an arrangement was made to connect the rotating shaft to the stationary load). No sparking could be observed under no load conditions. The imperfect contact and the consequent sparking appeared to be the reason behind the continuous lamp flicker. But this may be easily overcome using suitable mechanical designs. Two switches as is usual in D.C circuits were made to cut off the positive and negative supplies to the motor as and when required. The positive supply was cut off using the switch, the negative supply remaining undisturbed. Consequently the motor stopped. Under this condition, the shaft was connected to the ground though a 100W incandescent lamp. Instantly the shaft started rotating slowly even with the positive supply OFF. It was evident that the circuit of the motor was getting closed through the lamp. Since the 100W lamp flickered an attempt was made to make the current continuous by making use of series inductance. For this the LV side of a 230-12V/3A was connected in series with the lamp. The voltage at the HV terminal under no load was 50V. This was being induced as per the relation $e=-Mdi/dt$, di/dt being the rate of change of current owing to the flickers. This voltage would light up a 5W LED lamp, though with a lot of flickering. A 2.5µF was introduced in parallel with the HV side to make the voltage steady. It was observed that though the brightness of the lamp appeared to remain unaltered, it underwent alternate cycles of 'bright-dark' period, the dark period being greater than the bright one. It was obvious that the LED was receiving the voltage in '*pulses*'. A line tester 'touched' with the rotating shaft glowed, but surprisingly when connected with the collecting rod did not glow though both ought to remain at the same potential. While running at rated speed with rated terminal voltage of 230V, the current drawn by the fan motor was found to be 250±1mA. Surprisingly when the shaft was supplying a load of 100±.5mA to an incandescent lamp connected between the rotating shaft and the ground, no change in current drawn by the motor was apparent. The speed did not alter either. It was also observed that fluctuations in current supplied from the shaft had no effect on the main motor current.

Another experiment, similar to the above one was conducted using a *relatively newer* D.C fan manufactured in 1995. The no load voltage between the shaft and the ground, the polarity depending on the supply polarity as mentioned earlier. When this voltage was fed in to strong brine solution directly, it instantly dropped below. 8V and therefore proved to be of little use. But when the same voltage was fed at the input terminals i.e. A.C terminals of a bridge rectifier and then the rectified output was fed in to the same solution, bubbles became visible at the cathode and the terminal voltage was found to be 2±.1V D.C. delivering a current of 2.5±.05mA to the solution. Yet the voltage at the rectifier input was below 1V. So clearly the bridge rectifier in this case was causing *voltage magnification*. A LED (used in battery operated torches) would light up at this voltage. However a torch bulb having a tungsten filament rated 3V/2.5W would refuse to glow. A capacitor connected at the D.C terminals caused reduction in voltage and proved to be of no use. In this situation too the current supplied by the energized shaft would not add up with the current drawn by the motor from the D.C supply of 230V.

Observations

In case of the table fan driven by a single phase induction motor, the shaft voltage was quite low. Yet it appeared to be a potentially stable power source for low current electrolysis and LED lighting. Electric clocks requiring low voltage and current of the order of microamperes may also harness it. The voltage magnitude depended on polarity of the supply i.e. the positions of live and neutral wires. So the choice of polarity in order to make the source potential is crucial.

The D.C fan provided voltage of the order of 100V which is equivalent to the output of a half wave rectifier fed from a 230V single phase A.C source. So it proved to be useful for lighting loads for e.g. incandescent lamps. A curve was plotted showing the variation of shaft voltage at no load and at a standard resistive load of 100W with variations of supply voltage to the main motor *viz*.

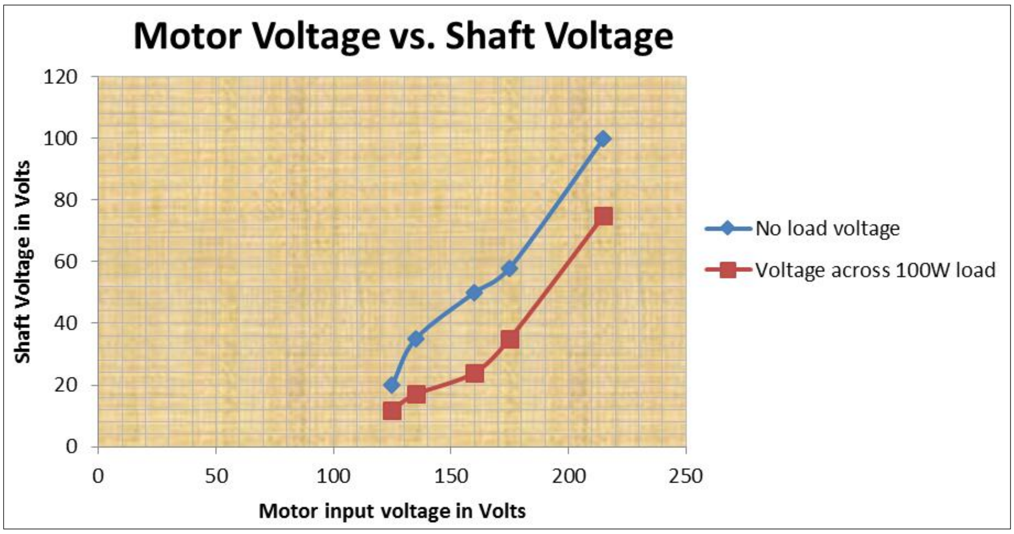

Fig 1: The curve representing the load characteristics is well below the one at no load under all circumstances. On plotting the percentage regulation w.r.t input voltage

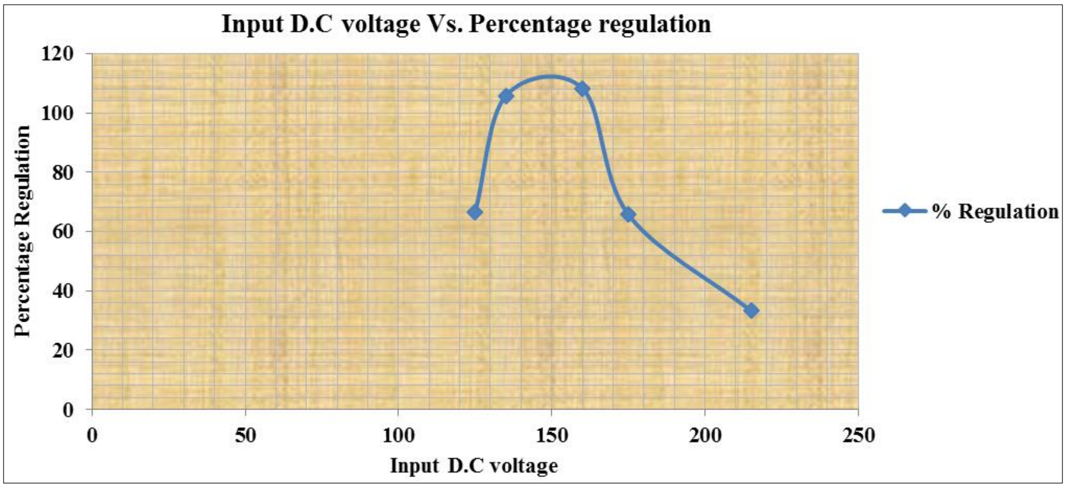

Fig 2: It is evident that the regulation curve is quite irregular. The shaft voltage at no load was plotted against varying values of capacitances keeping supply voltage to the motor constant at 230V D.C *viz.*

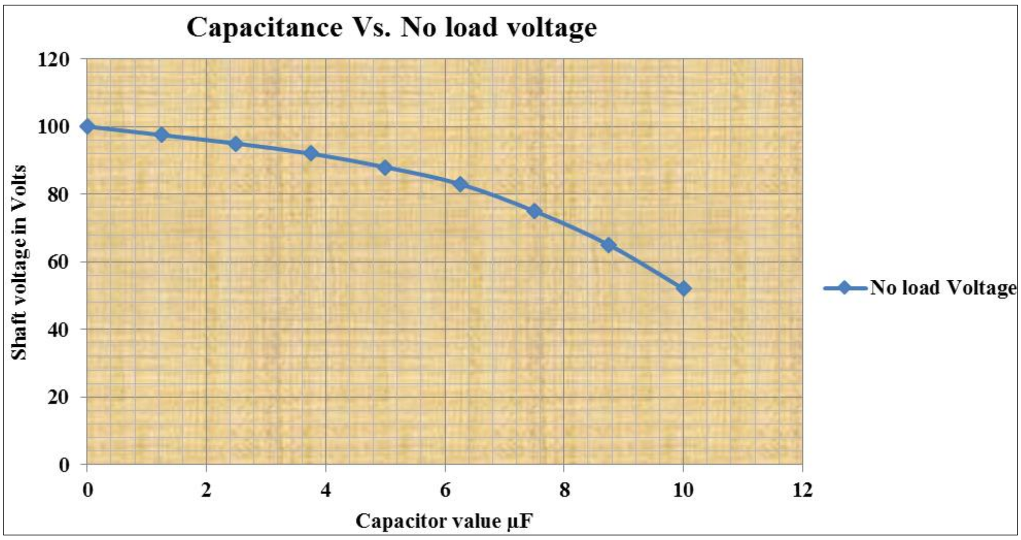

Fig 3: This is approximately a straight line with a negative slope. Hence no load voltage is low for high valued capacitances. The load vs. shaft voltage characteristics were plotted keeping the motor input voltage fixed at 230V D.C

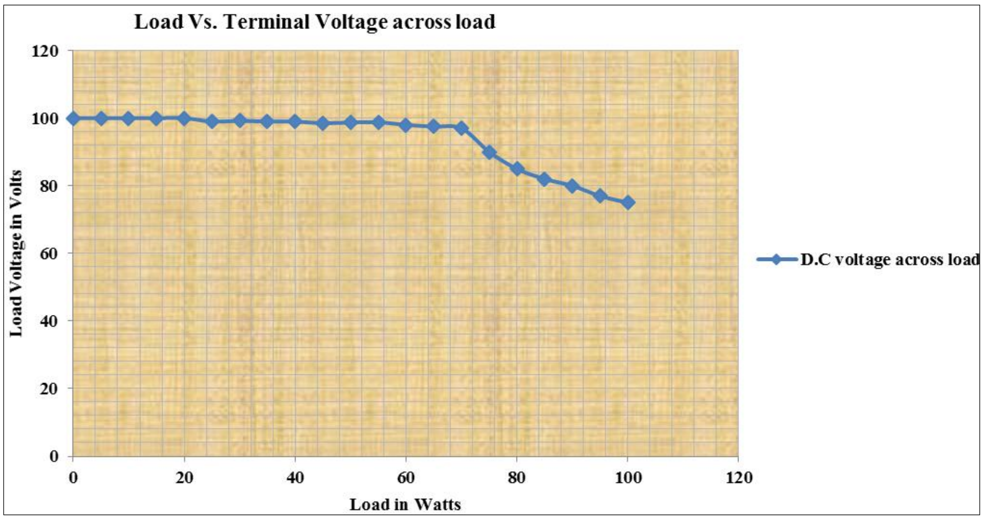

Fig 4: The limit upper limit of load to which the voltage remains almost constant is largely dependent on the condition of the motor. However a load of the order 60W may be easily supplied without excessive drop in voltage. A transformer utilizing the fluctuations in the current supplied by the shaft has a high regulation at the HV terminals. The curve below shows the variation of HV voltage with load:-

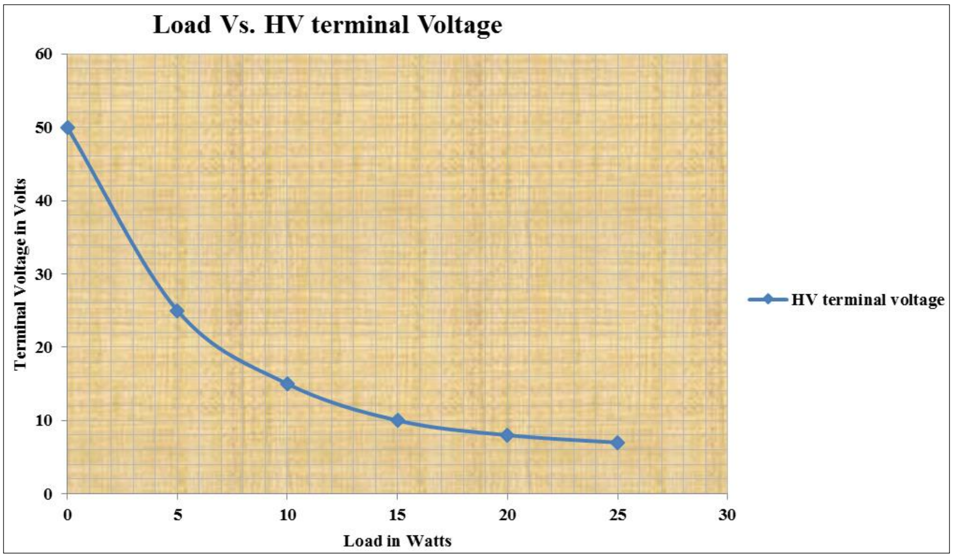

Fig 5: From the rectangular hyperbolic nature of the curve it may be inferred that the HV terminal voltage is almost inversely proportional to the load. The voltage tends to remain constant after a certain *critical load* the value of which depends on the winding characteristics of the transformer.

In case of a motor with a relatively better insulation, the shaft voltage is much lower in magnitude at no load. This too is dependent on the input voltage *viz*.

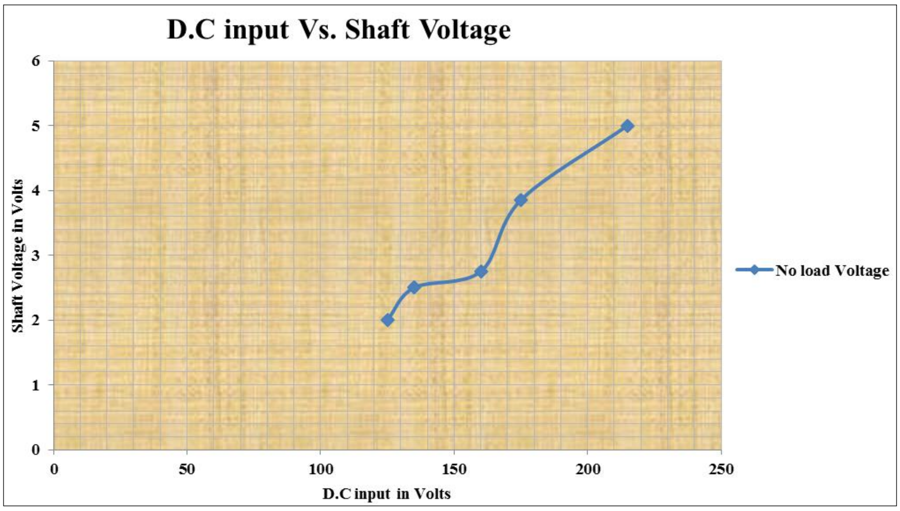

Fig 6

Results and Discussions

Shaft voltage is present in almost all motors. The following points are noteworthy:

a) A voltage whatsoever small in magnitude is present at the shaft of rotating motors, both A.C and D.C. This voltage may be sensed by an ordinary voltmeter with one terminal grounded.

b) For A.C motors the voltage is alternating in nature bearing the same frequency as that of the supply. The *magnitude which strictly depends on the polarity* indicates that *leakage is the predominant reason behind this voltage.*

c) The voltage after rectification is capable of supplying small D.C loads consuming power of the order of mW. Here the rectifier not only acts as a conversion device but also as an electrical isolator.

d) In case of direct current motors the voltage is D.C in nature.

e) The polarity of the voltage w.r.t ground depends on the supply polarity indicating that armature leakage is the main reason behind this. However capacitive coupling is also present.

f) Leakage mentioned above occurs at the armature brushes, either positive or negative. Hence *the voltage is equivalent to the out put of a half wave rectifier*.

g) The current drawn by the motor remains independent of the load supplied by the shaft under all circumstances.

h) Capacitance, used as a filter in rectifier applications is detrimental in the sense that it lowers shaft voltage. The load works far better when no capacitor is put in parallel.

i) With one of the supply leads (either positive or negative) cut off, the motor rotates at a lower speed when the shaft is grounded. In this case only one half cycle of the input A.C to the motor rectifier is utilized leading to lower speed.

j) In case of D.C motors with slightly better insulation the shaft voltage is much lower in magnitude, the polarity as usual depending on supply polarity.

k) Though the voltage is D.C in nature, yet a *bridge rectifier is necessary in such a case to perform impedance matching to a certain extent*. This improves the regulation and allows supply of current which otherwise would cause excessive drop in voltage.

Conclusion

Voltage available from the rotating shaft of electrical motors if cautiously harnessed may serve as a potential source of power. The extent of utilization depends on the conditions of the motor, esp. on the conditions of

The insulation. '*Aged'* D.C motors are highly potential and are capable of supplying currents of up to 1A maintaining voltages of the order 60-70V. However special arrangements have to be made for collecting current from the rotating shaft while driving the blades at the same time. A.C motors too are capable of supplying power at much lower voltages of the order of 5V and currents in the range of a few mA at the most.

Acknowledgements

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