An Innovative Technique for Optimization of Efficiency of Transformer and Inductor

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An Innovative Technique for Optimization of Efficiency of Transformer and Inductor

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Abstract*: In modern industrial era demand for electricity is increasing, as a result there is a rapid increase in demand for power generation and transmission. Various researches are going on in order to deliver the efficient energy systems. One such effective method for optimizing the efficiency of inductive devices such as transformer and inductors in cost efficient way has been discussed in this paper. Inductive circuits are used in all electronic devices; the values of impedance of this circuit determine the total efficiency of an instrument or a device. The significant loss in the transformer is the leakage of magnetic flux and Eddy current. By introducing a filler material, which is abundantly available in the earth's crust; these losses can be minimized. An amorphous filler material which has high permeability and lower electrical conductivity is introduced in the air gap of soft-core iron transformer which significantly reduces the magnetic flux leakage through the lateral sides of the transformer, in turn, enhances the magnetic coupling between the primary coil and the secondary coil of the transformer. Thus, the varying magnetic field around the coil is utilized to the possible extent, as a result the efficiency of a device is optimized. A prototype of a step-down transformer using this filler material has been designed in which the efficiency is increased by 8.306% when compared to the traditional transformers used today. The main contribution of this research is the introduction of a technique for optimizing the magnetic coupling between the primary and secondary coils, which imparts greater efficiency to the transformer and minimizes the overall transformer materials and production cost.

Index Terms*: leakage of magnetic flux, Eddy current, air gap, magnetic coupling.

I. INTRODUCTION

In modern Industrial era the demand for electricity is increasing exponentially with each passing day, as a result there is a rapid increase in the power generation and transmission network all over the world. Transformer forms a vital component in the avionics, power transmission and regulation system. At present, the electrical society has a numerous challenge in the optimization of the components used in the electrical and electronic circuit.

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Various researches are going on to deliver the most compact, highly efficient and cost-effective systems. To achieve greater efficiency, the significant loss in the traditional transformers has to be reduced by a modern method, which has been discussed in this paper. The overall transformer manufacturing cost minimization is addressed in this technical literature. On the other hand, the main approaches deal with the optimization of the efficiency and minimization of specific transformer cost components, such as the cost of magnetic material and the active part cost. This technique can also be used for inductors to achieve greater impedance. This technique is useful to manufacture inductors with high impedance and small size, which forms an excellent application in avionics industry. An amorphous ferromagnetic material has to be introduced to the core of the inductor or transformer to achieve the optimum magnetic coupling between the windings of the copper. This amorphous material can either be processed to get a solid core or can be filled in the air gaps of the transformer to increase the strength of the induced magnetic field from the windings on the primary coil.

II. DISCUSSION OF CONVENTIONAL TRANSFORMER WORKING AND LOSSES

A transformer works on Faraday's law of Electromagnetic induction, in which the varying current in the primary coil of the transformer produces a varying magnetic field. This, in turn, induces a varying electromotive force (emf) in a secondary coil, which is linked with the primary coil. To increase the strength of the magnetic field, a softcore iron or laminated silicon iron cores are used to wind those coils. This magnetic circuit is familiar as the "transformer core". It is designed to give a path for the magnetic field to move about, which is significant for the induction of the voltage between the two windings. Hence the electrical energy is transferred between two or more circuits through electromagnetic induction. However, this type of transformer structure where each winding is wound on separate limbs is not efficient because the secondary and primary windings are separated from each other. This results in a low magnetic coupling between the two windings and also large amounts of magnetic flux leakage from the transformer. By increasing and concentrating the magnetic field in the circuit around the coils, the magnetic coupling between the two windings will improve, but it also increases the magnetic losses of the transformer core. Hence, the usage of a single large chunk of the transformer is not desirable; instead, thin silicon steel laminations are preferred and used to diminish the Eddy current losses. This loss can be further reduced by using still smaller core materials.[1]

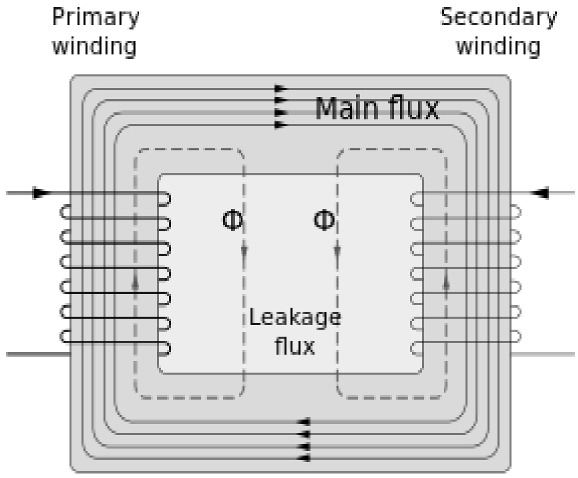

Fig 1. Sketch of a transformer.

III. PROPOSED METHODOLOGY

"Refined Iron Filings" is a material which has high permeability, low conductivity, amorphous in nature and accommodates a smaller cross-sectional area [2][9]. The iron filings are filled in the air-gaps present in the transformer where there is maximum leakage of the magnetic flux. Refined Iron Filings helps to reconstruct the connectivity of the weak magnetic field lines. This reluctance of the magnetic circuit has been reduced and hence provides maximum magnetic coupling between the primary and the secondary windings.

Advantages of using Iron filings are as follows.

1) Iron filings have a magnetic permeability (μ) of 1800, which is close to the magnetic permeability of the Iron. Hence filling Iron filings in the air gap of the transformer helps to reduce the reluctance of the magnetic circuit. This optimizes the Magnetic coupling between the primary and secondary coil. [2]
2) Iron filings have a thermal conductivity (k) of 47 to 80 W/m K, which is sufficient enough to transfer the heat produced in the transformer core to the surrounding environment. Hence this increases the operating cycle of the insulated copper wire. If not, owing to the excessive heat from the transformer the coating of the insulated copper wire would melt and results in dis-function of the circuit. [3]
3) Iron filings have an electrical resistivity of 2.5×10^{-6} to 5.0×10^{-6} Ωm, which is higher than the electrical resistivity of the silicon steel transformer core material (6.9×10^{-7} Ωm), this significantly reduces the loss in the transformer in the form of circulating Eddy current. [2].

IV. DESIGNING OF PROTOTYPE

Based on this proposal a prototype was designed and simulated. The detailed procedure of the same has been discussed below.

A. *Extraction and purification of Iron Filings*

Iron Filings are formed in the earth crust during the fragmentation of rock. Since it is insoluble in water, it is washed away by rainwater and deposited in the low-lying area. It can be easily extracted by running strong magnetic pieces in the soil. An amorphous grey colored material that is attracted to the magnet is separated and sewed to obtain fine dust of Iron Filings [2]. Then it is washed with water to remove water-soluble inorganic impurities and dried. Further, it is washed with acetone to remove organic impurities. Then, refined iron fillings are obtained, 200 grams of such a sample is used to make the prototype.

Fig 2. Refined Iron Filings

B. *Selection of transformer and rectifier*

Commercially available 6 W, 500mA Multi-tapped 230 V step-down transformer has been used with a switching option of 3V, 6V, 9V, 10V, and 12V AC. To convert alternating current to direct current for the ace of measurement, a bridge rectifier was designed with four Zener diode, one desired capacitor, and one resistor. So that the overall resistance of the bridge rectifier circuit comes to 24Ω. Schematic representation of the same has been shown below.

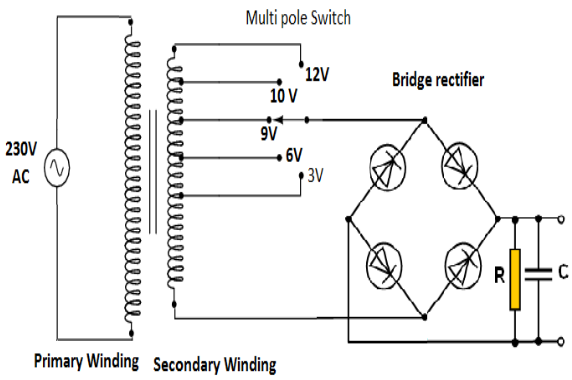

Fig 3. Circuit Diagram of prototype

V. SIMULATION OF PROTOTYPE

Based on the above circuit diagram a prototype of the proposal has designed and placed in a small plastic container of dimension 6 cm X 6 cm X 9 cm. A series of simulations has performed on the conventional transformer to compare the efficiency of the proposed technique. A photograph of the transformer is shown below, which is under simulation without the filings of iron. The output potential difference shown in the multimeter from the 230 V step-down transformer with the switch tapped to 10 V DC was observed to be 9.6V DC. This test was performed without the use of iron filings.

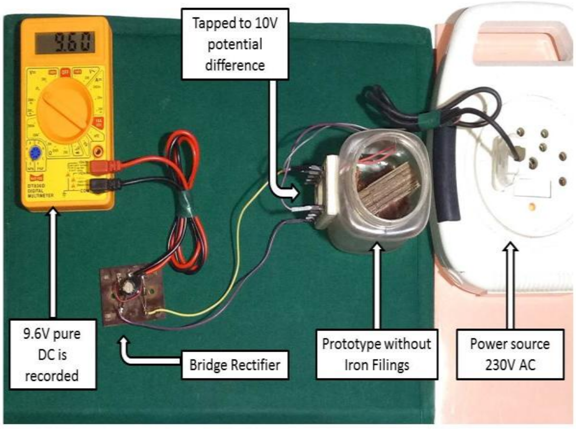

Fig 4. Simulation of prototype without Iron Filings

Further, the same simulations have been performed with 200 grams of Iron filings filled around the transformer to fill the air gaps. A photograph of the transformer is shown below, which is under simulation with the filings of iron wrapped around the transformer. The output potential difference shown in the multimeter from the 230 V step-down transformer with the switch tapped to 10 V DC was observed to be 10.40V DC. This test was performed with the use of iron filings. This shows an 8.1% increase in the steady output current when compared to the results obtained from the transformer without Iron Filings.

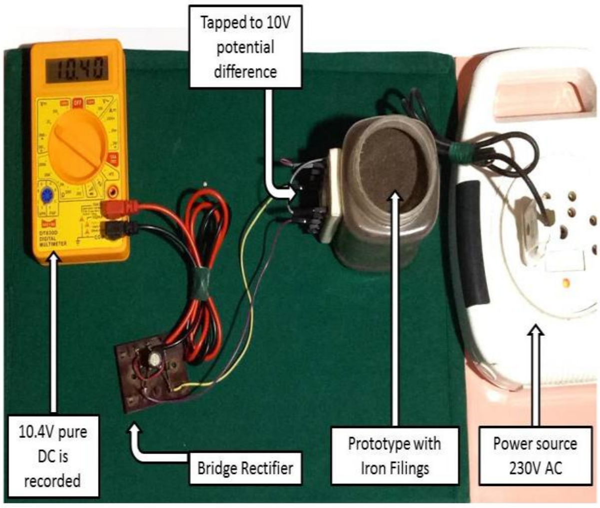

Fig 5. Simulation of prototype without Iron Filings.

VI. RESULTS AND DISCUSSION

Results of the simulation with various voltage tapping have been recorded before and after the introduction of Iron filings to the transformer (shown in table 1). An average of 8.306 % hike is observed in the output direct current. Hence, as a result of implementing this technology efficiency of a transformer have been increased significantly. As seen in Fig 5 the output of the transformer is higher than the desired output value by 0.4V. This can be rectified in the design of the transformer by reducing either the number of copper turnings or core material of a transformer. Hence by using Iron filings which are relatively cheaper than the copper and silicon steel, the cost involved in the bulk production of a transformer can be reduced significantly [7].

Table 1: Shows DC output from the transformer in different conditions

Tapped voltage in the Transformer	DC output observed (without Iron Filings)	DC output observed (with Iron Filings)	*Percentage of deviation*
3V	2.90V	3.13V	7.93%
6V	5.89V	6.37V	8.15%
9V	8.82V	9.58V	8.62%
10V	9.60V	10.40V	8.33%

Average of 8.306 % increase in the output current is observed (A slight variation can be seen between selected voltage tapping and the output DC voltage without Iron Filings. This is a result of introducing passive elements in the bridge rectifier)

VII. APPLICATION OF THE PROPOSED TECHNIQUE

The same technique can be used to increase the efficiency of the inductors. Filling refined iron Filings in the core of the inductor impedance of the circuit can be improved. This increases the capacity of storing more magnetic energy in the inductor [5]. As a result of implementing this technique, the size of the inductor can be reduced and the operating cycles of the inductor can also be enhanced. For the same output impedance, the size of the modified inductor is much smaller than a conventional inductor; which is beneficial improvement with respect to aeronautics as inductors are an integral part of the avionics, constituting as much as 30% of the all the components [6] [8].

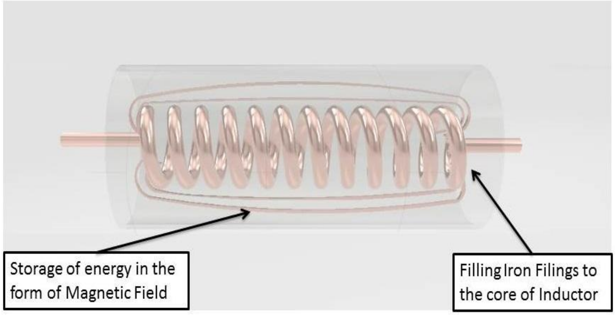

Fig 6. Schematic representation of Inductor

VIII. CONCLUSION

The proposed method is innovative and effective in increasing the efficiency of the transformer in a cost-efficient way. A series of simulation illustrate the validity of this method. This is a proven effective technique in reducing the losses in the transformer which occur due to the leakage of magnetic flux and Eddy current. This technology can be easily implemented in the production of small transformers.

This is a promising technique for the development of super-inductors, which has more energy density and probably be the best solution for energy storage in future.

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Dr Manoj Veetil graduated B. Tech in Aerospace Engineering from Indian Institute of Technology, Bombay, Master of Engineering degree in Aerospace Engineering from Imperial College London and holds PhD degree in Aerospace engineering specialized in Aerodynamics from Cranfield University, in the United Kingdom. He has over 18 years of teaching and 15 years in Industry, Research experience in both teaching UG and PG., He has presented papers at National and International conference and published papers in international publications. His teaching and research interest are focused on CFD and Aerodynamics.

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L Yethinder Ragav, studying B. Tech Aerospace engineering in IIAEM, Jain University, Bangalore. He has over 9 years of experience in working with electrical and electronic circuits, over 3 years of experience in designing and 3D printing. He has presented papers at international and national conferences and published a paper in international publications. His research interest is focused on Super Capacitors, 3D printing and Renewable energy.