Modelling of various rectifier flux pump topologies enabled by JcB switches

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***Abstract*—A Flux pump (FP) is a high current generating device for powering superconducting magnets. Based on their operating mechanism, they can be broadly classified into two types: dynamo FP and rectifier FP. In this paper we built the circuit models of various rectifier FP topologies, which uses DC field controlled HTS switches for the rectification purpose. The topologies are listed as: (i) half-wave retifier FP with a series resistance, (ii) half-wave rectifier FP with two switches, (iii) full-wave rectifier FP with four switches and (iv) full-wave rectifier FP with two switches. All these topologies are built within the MATLAB/Simscape platform using the predefined $I_c(B)$ look up tables. The results show the flux pumping phenomena for various topologies using the input sinusoidal current controlled source. The modelling results from the half-wave rectifier FP model with two switches are verified against the experimental results. A feedback controlled switching methodology of the applied field switch for maximised operating efficiency is proposed for the first time in this paper. The maximum efficiency values achieved for various topologies are tabulated for comparison purpose. This models presented in this paper helps to understand the rectifier FP operating mechanism and also to optimise the FP design for the appropriate load characteristics.**

***Keywords*—circuit model, flux pump, rectification, HTS, simscape, superconductors** *(key words)*

I. Introduction

High field magnets are currently being used in several applications like fusion energy, magnetic levitation, energy storage, power generation, high energy and nuclear physics, as well as medical applications. These high field magnets are made from superconductors and need large currents to energise them. These currents can range from 100's of Amperes to several 100's of kA. The conventional power electronic amplifiers for such high currents are not only expensive, but also bulky and will dissipate large amounts of energy. Also as most of these power electronics are designed to be operated at room temperatures, bulky copper current leads are needed to transfer the current from room temperature to cryogenic temperatures. These leads in turn will add more heat load into the cryogenic environment, making the entire process highly inefficient.

Flux pump's can be a ideal alternative to these conventional power electronic current sources. A flux pump when connected across a load, will make a closed loop and incrementally increases the flux within the loop, thus increasing the net current in the load. The time constant (L/R) of the loop needs to be high, such that the incremental current input is more than the dissipation. For reducing the effective resistance of the loop, all the elements in the flux pump and the load needs to be superconducting. These flux pumps are compact, will operate in cryogenic environment, thus adding no external heat leak due to the current leads from room temperature.

Depending on the superconducting material used, flux pumps can be broadly classified into low temperature superconductor (LTS) FP's and high temperature superconductor (HTS) FP's [1], [2]. Also based on the operating principle, flux pumps are further classified into dynamo based FP's and rectification based FP's. In this paper, we are discussing only about the HTS rectifier FP's. The experimental demonstration of both LTS and HTS rectifier FP's was already reported. Also, few attempts have been made to model these FP's in the literature, explaining the operating principle.

In this paper, we built the circuit models for the rectifier FP's and verified them using the experimental results. This paper also presents various circuit topologies for the rectifier FP, with an objective of improving the overall efficiency. The steady state efficiency values of all the topologies are evaluated

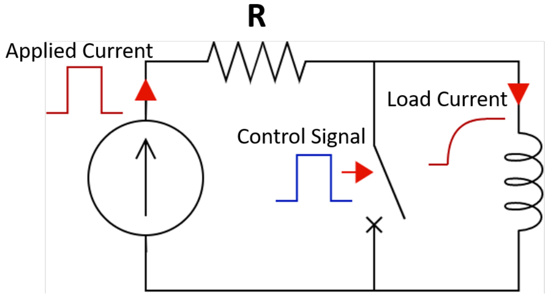

Fig. 1. Simplified rectifier flux pump model with series resistance, R and L being the inductance of the load. Here the superconducting switch is considered as an ideal switch and the resistance of the load is ignored. The control signal sets the switch to open during charging and closes while discharging, thus trapping the flux.

and tabulated for comparison purpose.

II. Experimental Setup

Figure 1 shows a simplified L-R circuit model of the flux pump, explaining the fundamental working principle. But in reality the high current source is made from step-down transformer, with copper as primary and HTS as secondary winding. The series resistance is realised by adding a copper tape, with a known resistance value. The parallel switch is made up of the HTS tape with a controlled external field applied across it. Similarly, the load coil is an insulated HTS double pancake coil.

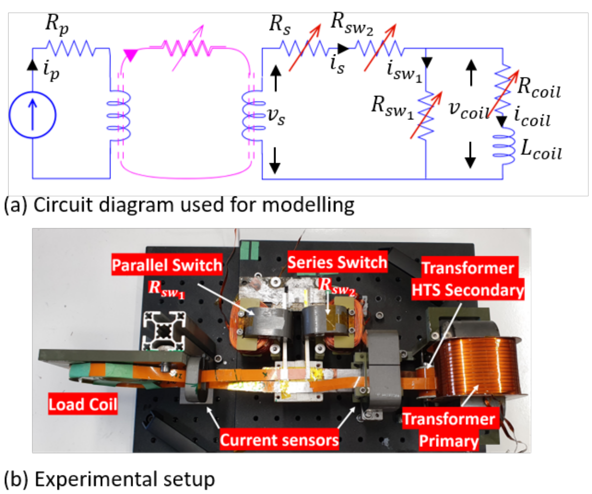

Fig. 2. (a) Circuit model of the half-wave rectifier used for modelling with the variables listed and (b) experimental setup used.

III. Results

An input sine wave with a peak to peak amplitude of 2 A is applied across the primary of the transformer as shown in Figure 2(a). An external field of 1 T as shown in Figure 3 is applied perpendicular to the HTS tapes to act as switches. From Figure 4, it is evident that the rectifier flux pump is working and the results are compared with the modelling results. These results demonstrate that the models are able to predict the flux pumping phenomenon. Similarly circuit models are developed for other topologies of the rectifier flux pump and the results will be detailed in this paper.

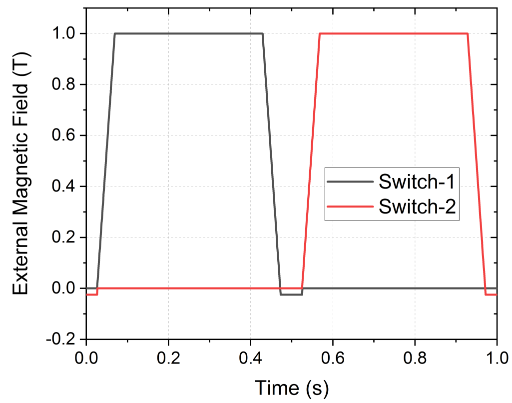

Fig. 3. Timed external field applied perpendicular to the HTS tapes to work as switches.

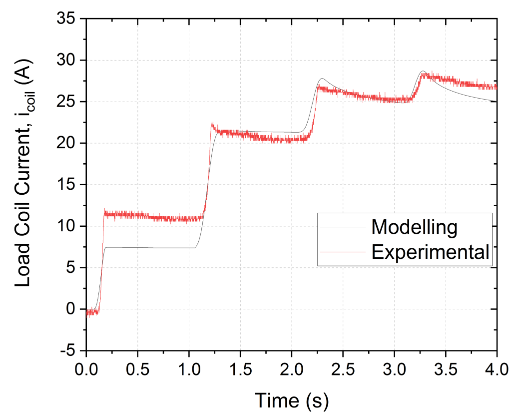

Fig. 4. Incremental increase of current in the load coil for every cycle, demonstrating the flux pumping phenomenon from both experimental and modelling results.

IV. Conclusion

Circuit models for the rectifier flux pump are developed and the results are validated against the experimental results. These verified circuit models are then used to develop high efficiency flux pumps while varying various other parameters. This paper for the first time presents a high efficiency ($>$ 90 %) flux pump model.

References

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