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Zero average flux tracking algorithm for high frequency transformers used in long pulse applications

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High voltage long pulse klystron modulators typically use pulse transformers, where the length of the pulse dictates the size of the transformer. Recent advancements in power electronics applied to modulator technology have, in order to facilitate multi-millisecond long pulse generation, instead suggests use of high frequency transformers in a high frequency pulse modulation/demodulation scheme, eliminating the size-pulse length dependency.

The stacked multi-level (SML) topology is built around this technique, where a cascaded power converters chain inverting, amplifying, rectifying and filtering the voltage following a capacitor bank charging stage to generate high voltage pulses. In a modulator built to European Spallation Source requirements, six such stages are connected in series at respective output, reducing stress on each module and increasing output ripple frequency, limiting the need of filtering, i.e. further reducing size, pulse rise time and stored energy.

While use of this topology has demonstrated reduction in modulator footprint and cost for typical long pulse applications, use of high frequency switching obliges strict transformer core flux control to avoid transformer saturation due to undesired dc voltage components generated by the inverter without transformer oversizing, hence maintaining high pulse-to-pulse accuracy and reproducibility.

Several methods implementing similar modes of control already exist, but commonly require additional sensors which may not be available or practical for inclusion in high voltage environments. Furthermore, available methods assume constant operation whereas the pulse-forming stage needs to systematically switch off completely between pulses, creating an additional problem related to remanent core flux and consequent inrush current; it must be ensured that flux is reset before the following pulse is to be generated, otherwise pulse-to-pulse flux accumulation will entail transformer saturation.

This paper describes the above problems in detail and outlines a practical algorithm, assessing its capability to control flux independent of pulse duration while maximizing rise time.

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