A Clamp-On Magnetic Field Energy Harvester for Self-Powered Dynamic Line Rating Sensor Nodes

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The increased integration of renewable energy resources into transmission networks has intensified power flow variability, exposing the limitations of static line rating methods that systematically underutilise conductor capacity by relying on conservative worst-case thermal assumptions. Dynamic Line Rating (DLR) offers a data-driven alternative through real-time environmental and electrical monitoring. However, its widespread deployment is constrained by the absence of viable, autonomous power solutions for sensor nodes situated in remote transmission infrastructure, where grid-connected supply is economically and logistically prohibitive and conventional battery systems impose recurring maintenance costs and environmental burdens. This study investigates a clamp-on Magnetic Field Energy Harvester (MFEH) as a fully self-sustaining power source for DLR sensor nodes, exploiting stray electromagnetic fields emanating from AC current-carrying transmission conductors, an energy source that is continuously available, unlike intermittent ambient sources such as solar or wind. The MFEH system comprises a toroidal inductive pickup coil, a rectifier, a four-switch buck-boost (FSBB) converter for power conditioning, and an ESP32 microcontroller is used to implement an impedance matching algorithm for Maximum Power Point Tracking (MPPT), enabling dynamic optimisation of energy extraction across varying conductor current magnitudes and load conditions. Harvested surplus energy is directed to a supercapacitor buffer to sustain operation during low-current contingencies. Experimental characterisation across distribution line currents ranging from 20 A to 80 A demonstrated harvested power levels between 80mW to 2280mW, with a peak conversion efficiency of 70.89% in the FSBB converter at fixed impedance operation. These results provided sufficient regulated output power to continuously operate the DLR sensor node while maintaining a stable 8 V supply. These findings establish that infrastructure-independent, self-powered DLR deployment is technically feasible, offering a scalable pathway to cost-effective grid instrumentation. By enabling continuous real-time line rating without external power dependency, this approach directly supports reductions in transmission congestion, curtailment of renewable generation, and advances the operational intelligence of smart grid infrastructure.

Keywords: dynamic line rating, energy harvesting, electromagnetic induction, maximum power point tracking, smart grid