ABSTRACT

Internet of Things is an ongoing trend in different fields, from transportation to industries, from smart agriculture to cities and from healthcare to wearables, enabling Industry 4.0 benefits. Wireless Sensor Nodes for real-time remote monitoring of assets allow the implementation of Condition Based Maintenance (CBM), enhancing safety, reliability and productivity. WSNs often require installation in hard-to-reach areas to sense specific vital parameters, absence of cabled power, compact form factor, cost effectiveness and being user friendly. Therefore, the easiest and most widespread power supply solution is primary battery that need to be replaced often. However, the number of deployed IoT devices is growing exponentially and is expected to overcome 30 billions by the end of 2030. It follows that the large-scale and disposal batteries is not feasible for costs and environmental damage, conflicting with the Paris Agreement goals. The use of energy harvesters as power supply in replacement of batteries could provide a valid solution and facilitate the widespread of IoT devices. This is possible thanks to technology advancements in energy harvester conversion efficiency and electronic components power consumption reduction. Energy harvester powered WSNs (EH-WSNs) are self-powered and energy-autonomous, do not require maintenance for battery substitution or recharging, are completely wireless, suitable for miniaturization and more sustainable. However, the unpredictable energy sources and ultra-low-power density need to be addressed correctly to effectively benefit from the use of energy harvesting.

This thesis focuses on the design of a gravitational vibrational electromagnetic energy harvester (GVEH) that exploits vertical random vibrations on-board of a freight train for health remote monitoring. The GVEH analytical model is proposed as a one-degree-of-freedom translational mass-spring-damper system. The generator uses an asymmetric one-sided magnetic spring for induction of electromotive force in coils via magnetic flux variation in time under external excitation. The non-linear characteristics of stiffness, damping and electromechanical coupling coefficient are obtained from numerical FEM simulations on Ansys Maxwell. The dynamic time-response of the system in terms of magnet displacement, induced voltage and generated power is simulated on Simulink. The device is optimized with numerical simulations and a prototype is designed for experimental validation. The optimized GVEH generates an RMS AC power peak of 39 mW in resonance conditions at 4 Hz, with an NPD of 2.54 and a FoMv of 10.9 %. A 2DOF GVEH configuration is studied to enhance the frequency bandwidth and conversion efficiency but shows lower power density and excessive volume.

The WSN hardware requires a power management circuit to rectify AC GVEH power and efficiently supply it to the battery and the load. Electronic components constituting the WSN circuit are chosen after experimental optimization in terms of rectification and storage power efficiency. The proposed circuit achieves a total power conversion efficiency (PCE) of 60 % at 0.5 g excitation amplitude from AC input to the output battery charge. Real train vibrations spectrum is analyzed to evaluate GVEH power generation in real working conditions. Mounting the GVEH on the bogie frame provides an average battery charge power of 3.31 mW. Considering the WSN power consumption and communication quality requirements to send data with adequate reliability, a duty cycle is defined to achieve energy neutrality operations. Sending one data per second results in a net positive charge to the battery and guarantees ideally infinite lifespan of the EH-WSN under real train vibrations. A battery-free configuration with a capacitor as storage unit is investigated with promising results.