Design of a Smart Maximum Power Point Tracker (MPPT) for RF Energy Harvester

Dilruba Parvin¹, Taeho Oh² and Syed K. Islam¹

¹Department of Electrical Engineering and Computer Science, University of Missouri, Columbia, MO 65201, USA.
²Department of Electrical Engineering and Computer Science, The University of Tennessee, Knoxville, TN 37996, USA.

Email: dpztv@mail.missouri.edu

Rapid advancement of portable and wireless technologies has led to the increased demand for power supply which is not being met with existing conventional energy sources. RF energy is a promising alternative to the conventional batteries due to its ample availability in nature and its ability to remotely powering electronic circuits. The power density of RF signal is relatively low compared to other available ambient energy sources and varies depending on the source. Thus, an efficient power management system is required to extract the maximum available power from RF signal. This paper presents design of a smart maximum power point tracking (MPPT) algorithm in order to attain improved efficiency for RF energy harvester.

MPPT is one of the most widely used power management techniques which ensures the operation of the system at maximum power point (MPP) with variable input power and thereby increases the efficiency of the energy harvester or renewable energy sources such as solar cell. Several algorithms have been developed to track MPP of a system. The algorithms developed for MPPT system can be divided as inline and offline algorithms [1]. In the case of inline algorithm such as perturb and observe (P&O), and incremental conductance (IC) the control signal is generated using instantaneous voltage or current values of the input signal. On the other hand, offline algorithm such as fractional open circuit voltage (FOCV), estimates the maximum power point voltage, $V_{mp}$ using the open circuit voltage, $V_{oc}$ of the system. Offline algorithms are relatively easier to implement but offer less precision compared to its inline counterpart. These conventional MPPT algorithms provide slow or inaccurate tracking under rapid variation of the input power. Therefore, a smart MPPT algorithm has been proposed to improve the efficiency of the RF energy harvester for rapidly varying input power by reducing the power loss and increasing the tracking speed and accuracy. Data will be collected from conventional FOCV based MPPT block to predict $V_{mp}$ using smart MPP tracker. The system level block diagram of RF energy harvester is presented in Fig 1. The RF energy harvester consists an active rectifier, a matching network, a DC-DC boost converter and an MPPT block. According to our previous work [2], the MPPT employed in this system follows the FOCV algorithm which estimates the operating voltage at maximum power as a function of the open circuit voltage of the source. The open circuit voltage of the rectifier serves as the reference voltage of the converter and determines its duty cycle. Thus, by changing the duty cycle of the converter, its input impedance can be varied and matched with the output impedance of the rectifier. Fig 2(a) and 2(b) represent the design and block level diagram of the FOCV based MPPT scheme, respectively. The MPPT block consists of an oscillator, a sample-and-hold (S&H) circuit and a comparator. The oscillator determines the sampling frequency of the S&H circuit. The S&H circuit (Fig. 3) samples and holds the output voltage of the rectifier. The converter has one NMOS switch and one PMOS switch. Fig 4(a) and 4(b) depict the low-side and high-side switch control schemes, respectively. By controlling the switching frequency of the converter, its input impedance can be matched with the output impedance of the rectifier. From Table 1 it can be seen that input impedance of the converter, $R_{input}$ is able to track the optimum output impedance of the rectifier, $R_{opt}$. The values of the output current and the voltage of active rectifier and the estimated $V_{mp}$ will be collected from the FOCV based MPPT controller (Fig. 5). The dataset will be divided into training and testing datasets. A fully connected neural network (FCNN) model will be used to predict $V_{mp}$ as neural networks are able to predict non-linear behavior [3]. The FCNN will be developed using machine learning packages such as Keras, TensorFlow etc. The number of hidden layers and neurons in each hidden layer will be determined by trial and error method. The developed model will be trained and tested using the training and testing datasets. The neural model with optimum accuracy will be implemented into hardware. The proposed neural network based MPPT system will reduce the power loss occurring at the open circuit condition of the FOCV method. Besides, it increases the tracking speed by training the smart MPPT model offline.
Figure 1: System level block diagram of RF energy harvester.

Figure 2: (a) Design and (b) block level diagram of the proposed MPPT scheme.

Figure 3: Sample-and-hold (S&H) circuit.

Figure 4: Control scheme of (a) low-side switch and (b) high-side switch.

Figure 5: Design of neural network based MPPT.

Table 1: Input Impedance of the Proposed DC-DC Boost Converter- Measured

<table>
<thead>
<tr>
<th>Input Power (dBm)</th>
<th>NMOS on time, t1 (μs)</th>
<th>Switching frequency, f_s (Hz)</th>
<th>R_input (kΩ)</th>
<th>R_opt (kΩ)</th>
<th>R_diff (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10</td>
<td>12</td>
<td>120</td>
<td>3.47</td>
<td>3.70</td>
<td>0.22</td>
</tr>
<tr>
<td>-7.5</td>
<td>11</td>
<td>169</td>
<td>2.93</td>
<td>2.70</td>
<td>0.23</td>
</tr>
<tr>
<td>-5</td>
<td>11</td>
<td>189</td>
<td>2.62</td>
<td>1.90</td>
<td>0.72</td>
</tr>
</tbody>
</table>

References: