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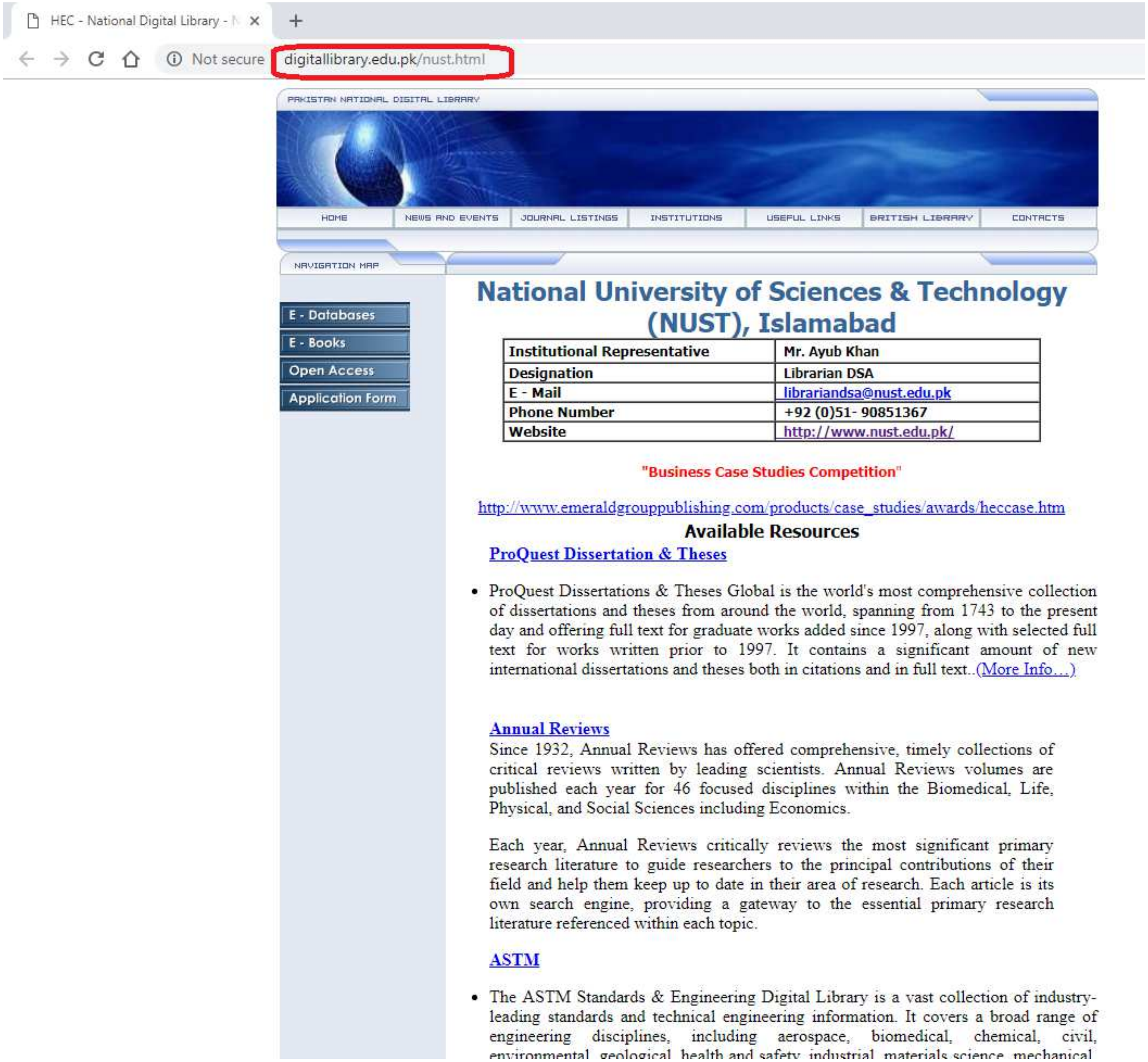

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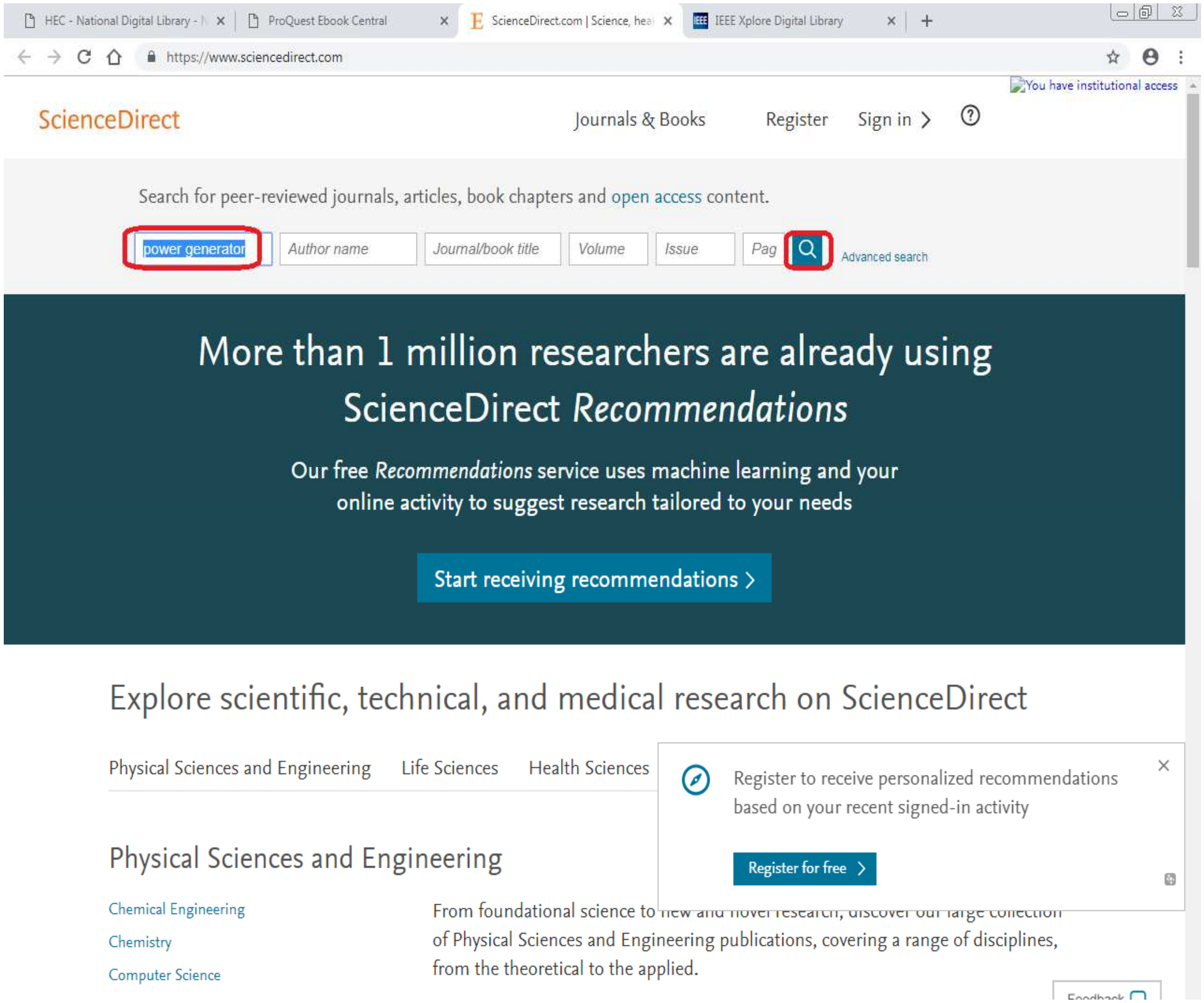

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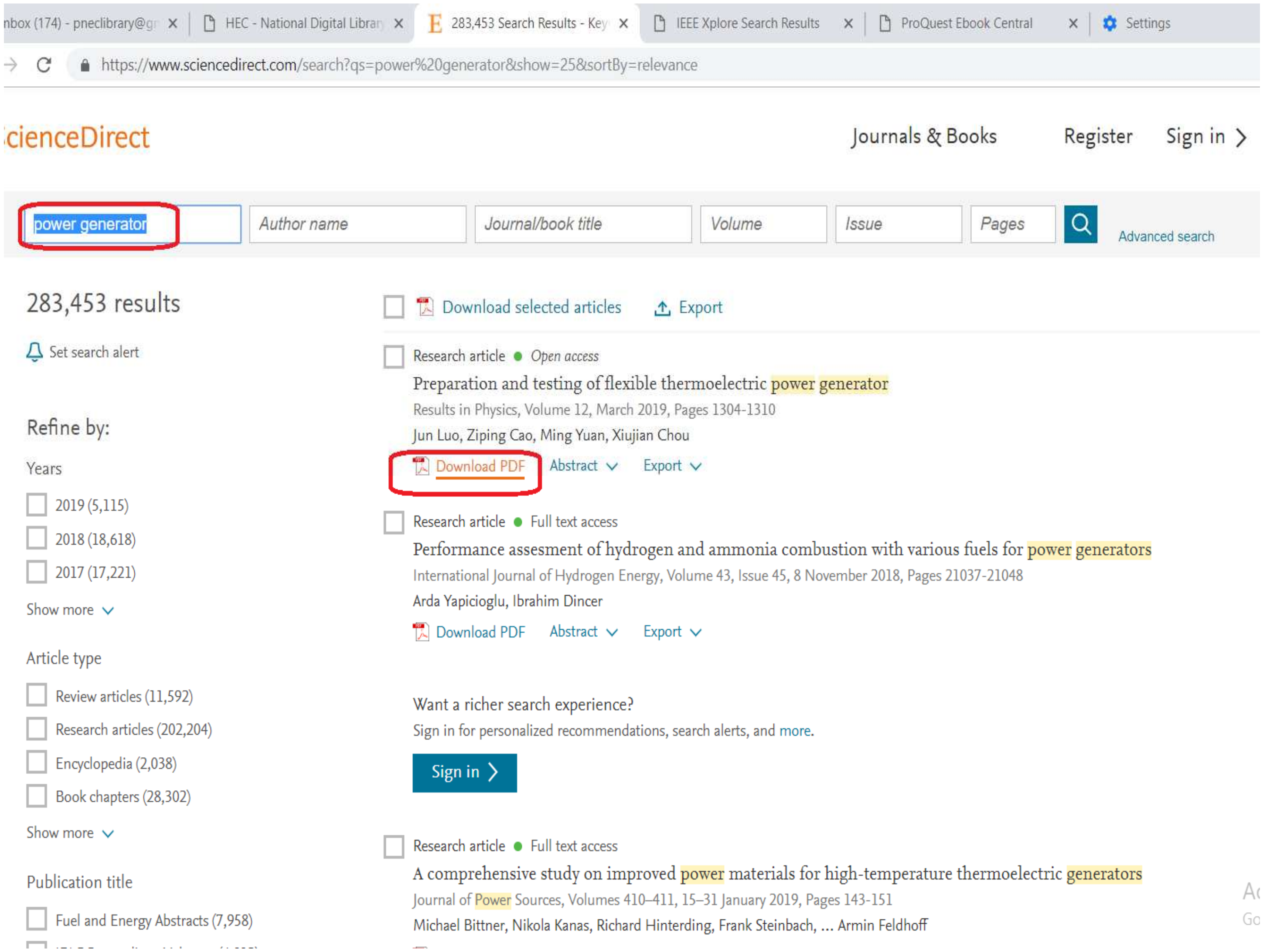

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Preparation and testing of flexible thermoelectric power generator

Luo Jun[a], Cao Ziping[a,*], Yuan Ming[b], Chou Xiujian[c,*]

[a] College of Telecommunications & Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China
[b] College of Automation, Nanjing University of Posts and Telecommunications, Nanjing 210003, China
[c] Sci & Technol Elect Test & Measurement Lab, North University of China, Taiyuan 030051, Shanxi, China

ARTICLE INFO

Keywords:
Flexible
Thermoelectric power generator
Evaporation current
Substrate temperature
Polyimide
Vacuum evaporation

ABSTRACT

Flexible thermoelectric power generator was fabricated by vacuum evaporation method. The effect of evaporation current and substrate temperature on the performance of thermoelectric films was investigated. When the evaporation currents were 100 A for *p*-type film and 110A for *n*-type film, the films exhibit (0 0 1) oriented which enhanced thermoelectric properties. The optimized power factor of the *p*-type films was found to be about 0.97×10^{-4} W/m·K^2 at the substrate temperature of 50 °C. The optimized power factor of the *n*-type films was found to be about 3.8×10^{-4} W/m·K^2 at the substrate temperature of 100 °C. The output voltage of flexible device with 11 pairs of p-n legs was measured. And the output voltage was 50 μV/K calculated from the slope, when the temperature difference was 100 K, the output voltage was about 50 mV.

Introduction

Thermoelectric devices have broad application prospects due to characteristics of small size, compact structure, no moving parts, no noise, and no pollution [1]. Most of the traditional thermoelectric devices have a sandwich structure, which can be used only on the surface of the flat structure. Therefore, the scope of application is greatly limited. As the market for wearable devices grows, providing continuous power to these wearable devices becomes an issue that needs to be addressed [2–7]. If the body's thermal energy can be effectively utilized, it can provide continuous electrical energy to these wearable devices. The wearable electronic device can convert the human body heat into electrical energy through a flexible thermoelectric device, thereby realizing a self-powered system [8,9]. Flexible thermoelectric devices have the advantage of low cost, bending resistance, strong durability, so it is more practical and more widely used [10–19]. In recent years, there have been many research reports on flexible thermoelectric devices [20–30]. Many researchers have combined thermoelectric power generation components with polymers to achieve the flexibility or extensible structure of the device. Fukuie et al. developed a stretchable thermoelectric power generation device using a rigid BiTe-based thermoelectric elements and a non-stretched substrate having a folded deformation [31]. Nuthongkum et al. prepared a flexible BiTe film by RF magnetron sputtering on a polyimide substrate using a Bi_2Te_3 target [32]. Flexible thermoelectric devices obtained by combining polymers with conventional thermoelectric elements are typically relatively thick. It is a good idea to prepare a flexible thermoelectric device on a polymer substrate by magnetron sputtering, but it is relatively expensive to manufacture. The vacuum evaporation method has advantages of lower fabricating expenses and short processing time for the fabrication of thermoelectric films [33]. In this work, flexible thermoelectric devices have been successfully fabricated using the vacuum evaporation method. A stable thermoelectric film was prepared on a polymer flexible substrate by using a simple, easy-to-operate, low-cost vacuum evaporation technique, and its structure, surface morphology, thermoelectric properties, and elemental composition were analyzed. The influence of substrate temperature on the film provides experimental basis for the application of Bi_2Te_3 film in flexible thermoelectric devices.

Experimental

The polyimide was cleaned with acetone and ethanol, and used as substrate. The $Bi_{0.48}Sb_{1.52}Te_3$ and $Bi_2Se_{0.3}Te_{2.7}$ powder obtained by smashing the $Bi_{0.48}Sb_{1.52}Te_3$ and $Bi_2Se_{0.3}Te_{2.7}$ ingot were used as evaporation source and evaporated from a tungsten boat. The thermo-

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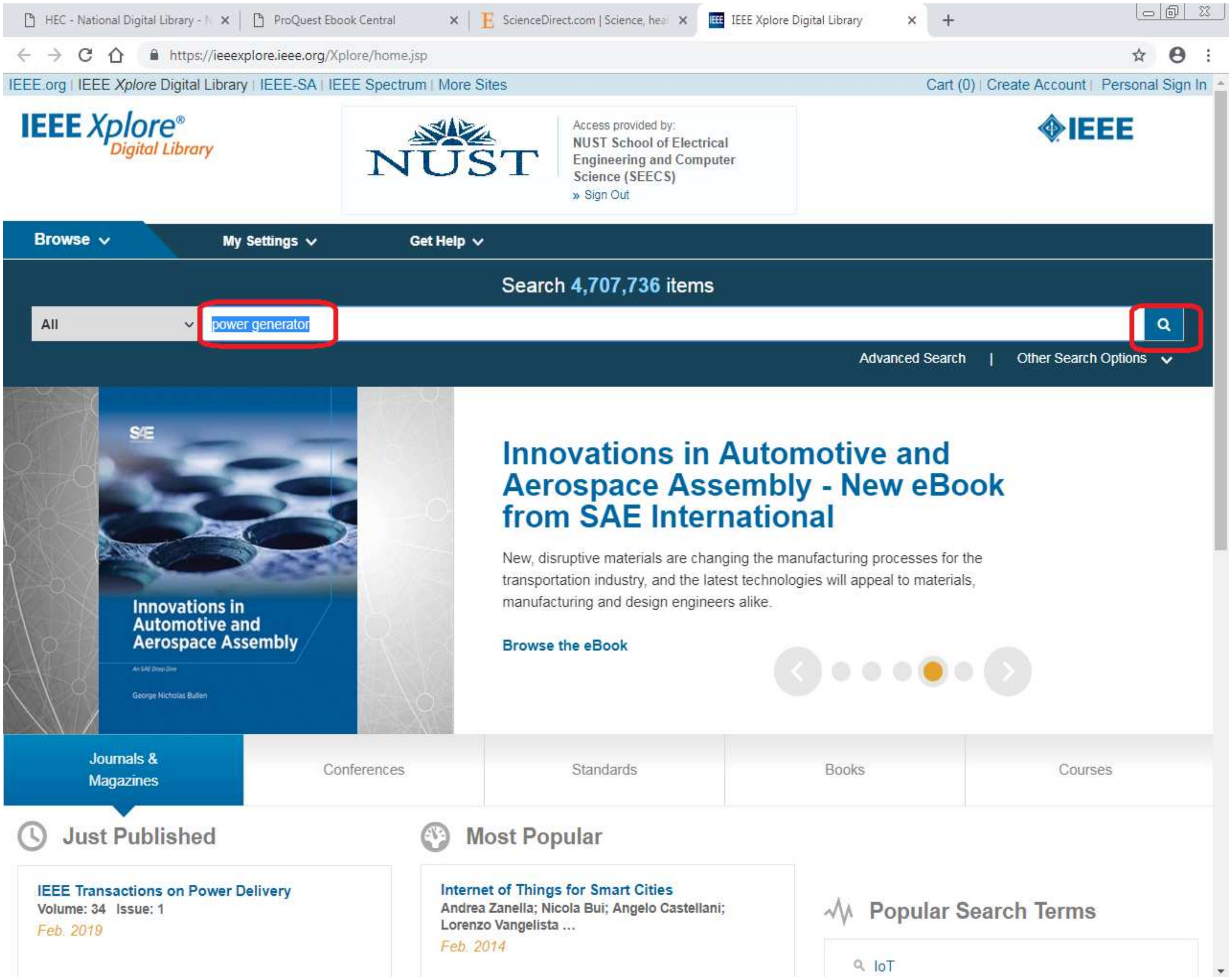

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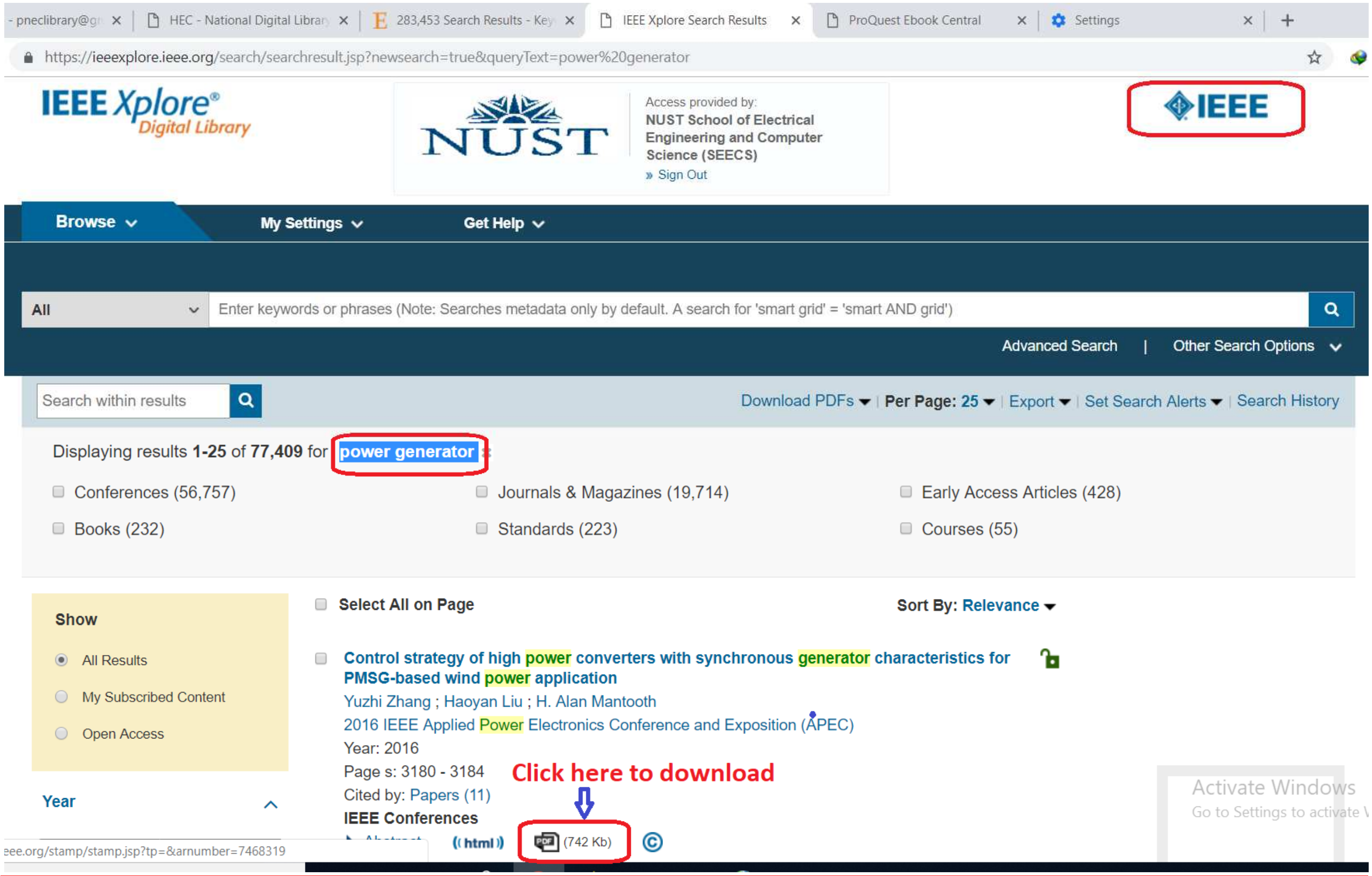

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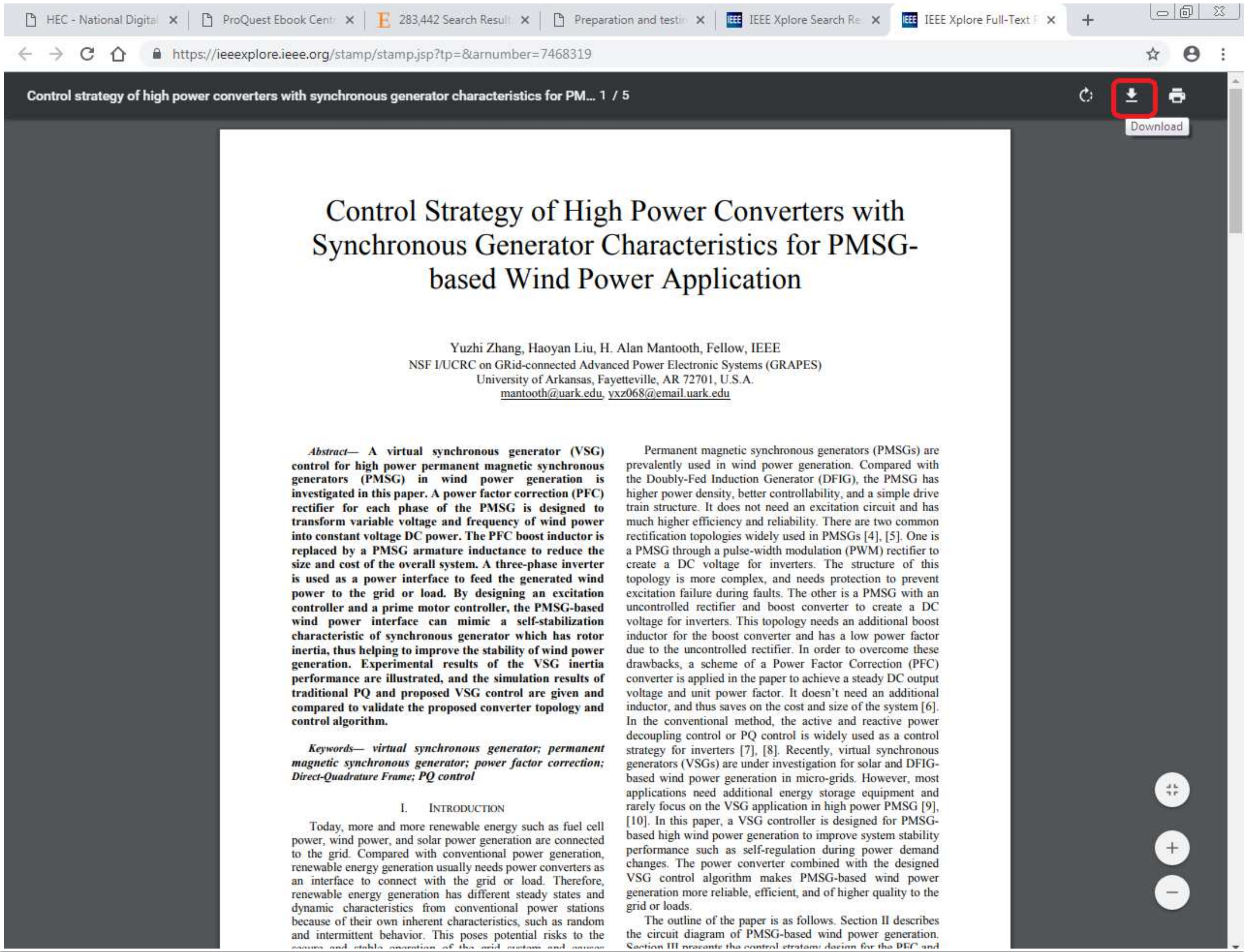

Control Strategy of High Power Converters with Synchronous Generator Characteristics for PMSG-based Wind Power Application

Yuzhi Zhang, Haoyan Liu, H. Alan Mantooth, Fellow, IEEE
NSF I/UCRC on GRid-connected Advanced Power Electronic Systems (GRAPES)
University of Arkansas, Fayetteville, AR 72701, U.S.A.
mantooth@uark.edu, yxz068@email.uark.edu

***Abstract*— A virtual synchronous generator (VSG) control for high power permanent magnetic synchronous generators (PMSG) in wind power generation is investigated in this paper. A power factor correction (PFC) rectifier for each phase of the PMSG is designed to transform variable voltage and frequency of wind power into constant voltage DC power. The PFC boost inductor is replaced by a PMSG armature inductance to reduce the size and cost of the overall system. A three-phase inverter is used as a power interface to feed the generated wind power to the grid or load. By designing an excitation controller and a prime motor controller, the PMSG-based wind power interface can mimic a self-stabilization characteristic of synchronous generator which has rotor inertia, thus helping to improve the stability of wind power generation. Experimental results of the VSG inertia performance are illustrated, and the simulation results of traditional PQ and proposed VSG control are given and compared to validate the proposed converter topology and control algorithm.**

***Keywords*— virtual synchronous generator; permanent magnetic synchronous generator; power factor correction; Direct-Quadrature Frame; PQ control**

I. Introduction

Today, more and more renewable energy such as fuel cell power, wind power, and solar power generation are connected to the grid. Compared with conventional power generation, renewable energy generation usually needs power converters as an interface to connect with the grid or load. Therefore, renewable energy generation has different steady states and dynamic characteristics from conventional power stations because of their own inherent characteristics, such as random and intermittent behavior. This poses potential risks to the

Permanent magnetic synchronous generators (PMSGs) are prevalently used in wind power generation. Compared with the Doubly-Fed Induction Generator (DFIG), the PMSG has higher power density, better controllability, and a simple drive train structure. It does not need an excitation circuit and has much higher efficiency and reliability. There are two common rectification topologies widely used in PMSGs [4], [5]. One is a PMSG through a pulse-width modulation (PWM) rectifier to create a DC voltage for inverters. The structure of this topology is more complex, and needs protection to prevent excitation failure during faults. The other is a PMSG with an uncontrolled rectifier and boost converter to create a DC voltage for inverters. This topology needs an additional boost inductor for the boost converter and has a low power factor due to the uncontrolled rectifier. In order to overcome these drawbacks, a scheme of a Power Factor Correction (PFC) converter is applied in the paper to achieve a steady DC output voltage and unit power factor. It doesn't need an additional inductor, and thus saves on the cost and size of the system [6]. In the conventional method, the active and reactive power decoupling control or PQ control is widely used as a control strategy for inverters [7], [8]. Recently, virtual synchronous generators (VSGs) are under investigation for solar and DFIG-based wind power generation in micro-grids. However, most applications need additional energy storage equipment and rarely focus on the VSG application in high power PMSG [9], [10]. In this paper, a VSG controller is designed for PMSG-based high wind power generation to improve system stability performance such as self-regulation during power demand changes. The power converter combined with the designed VSG control algorithm makes PMSG-based wind power generation more reliable, efficient, and of higher quality to the grid or loads.

The outline of the paper is as follows. Section II describes the circuit diagram of PMSG-based wind power generation.