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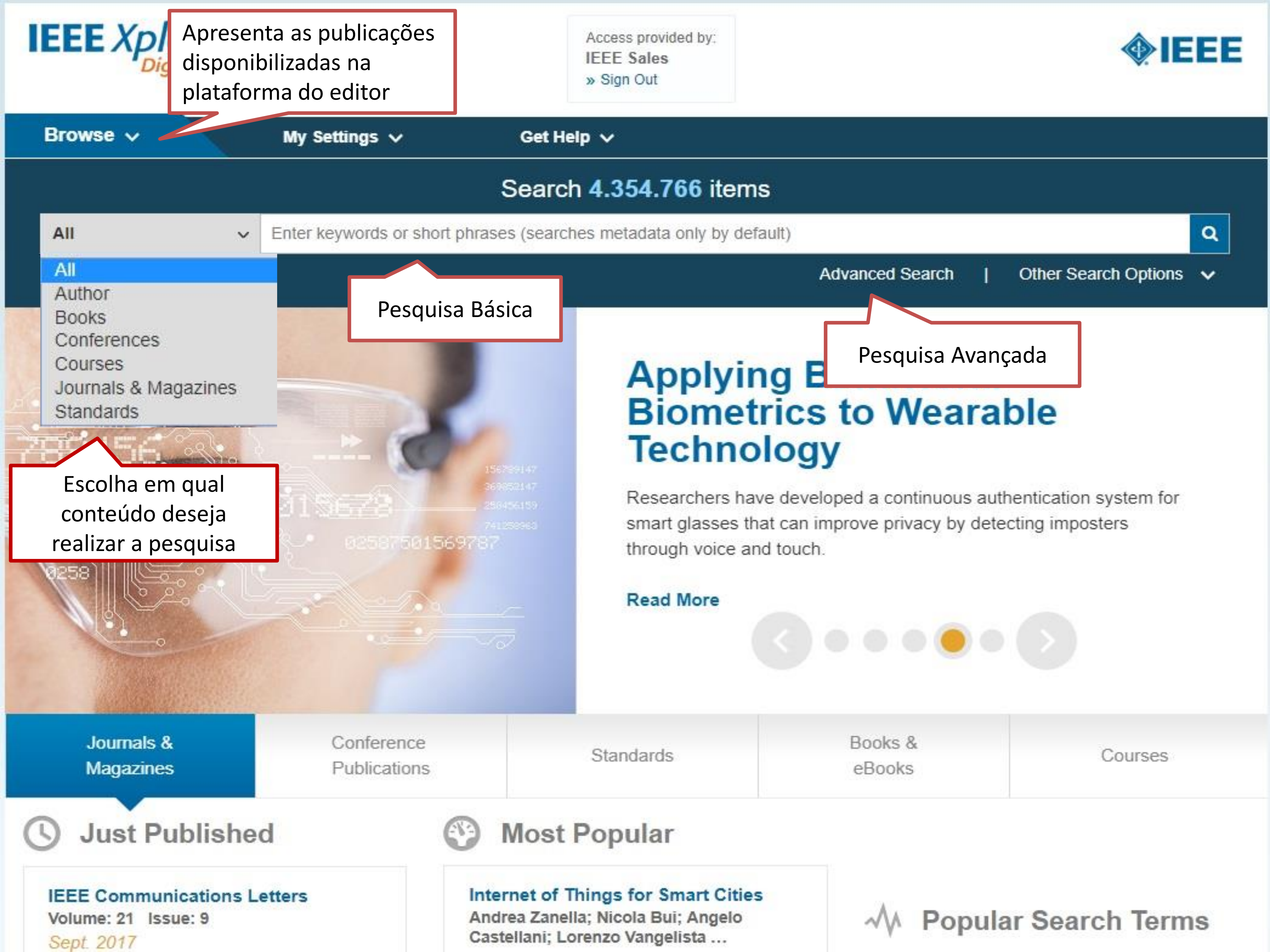

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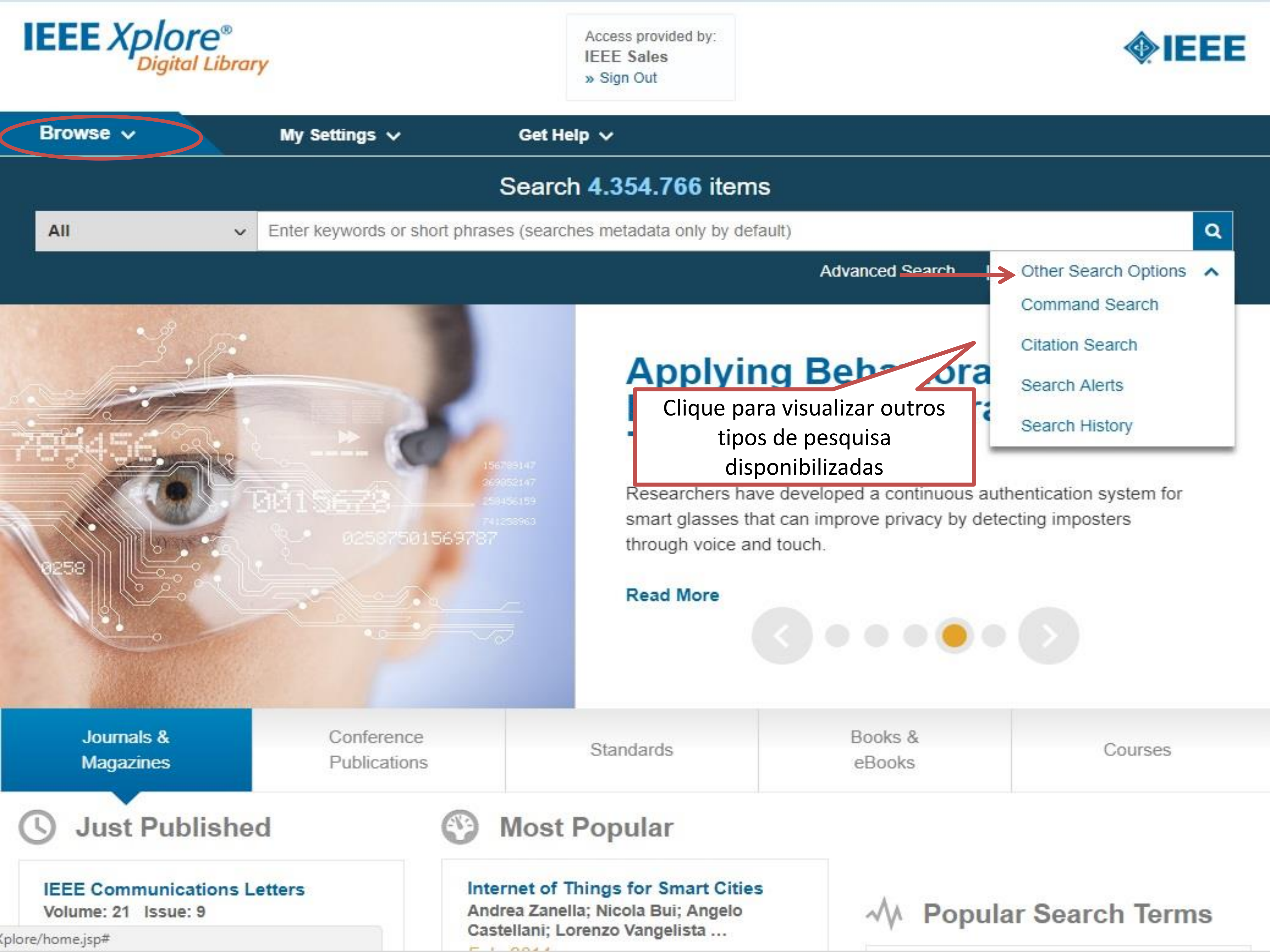
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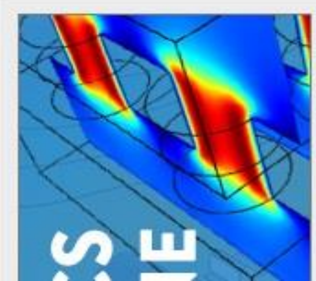

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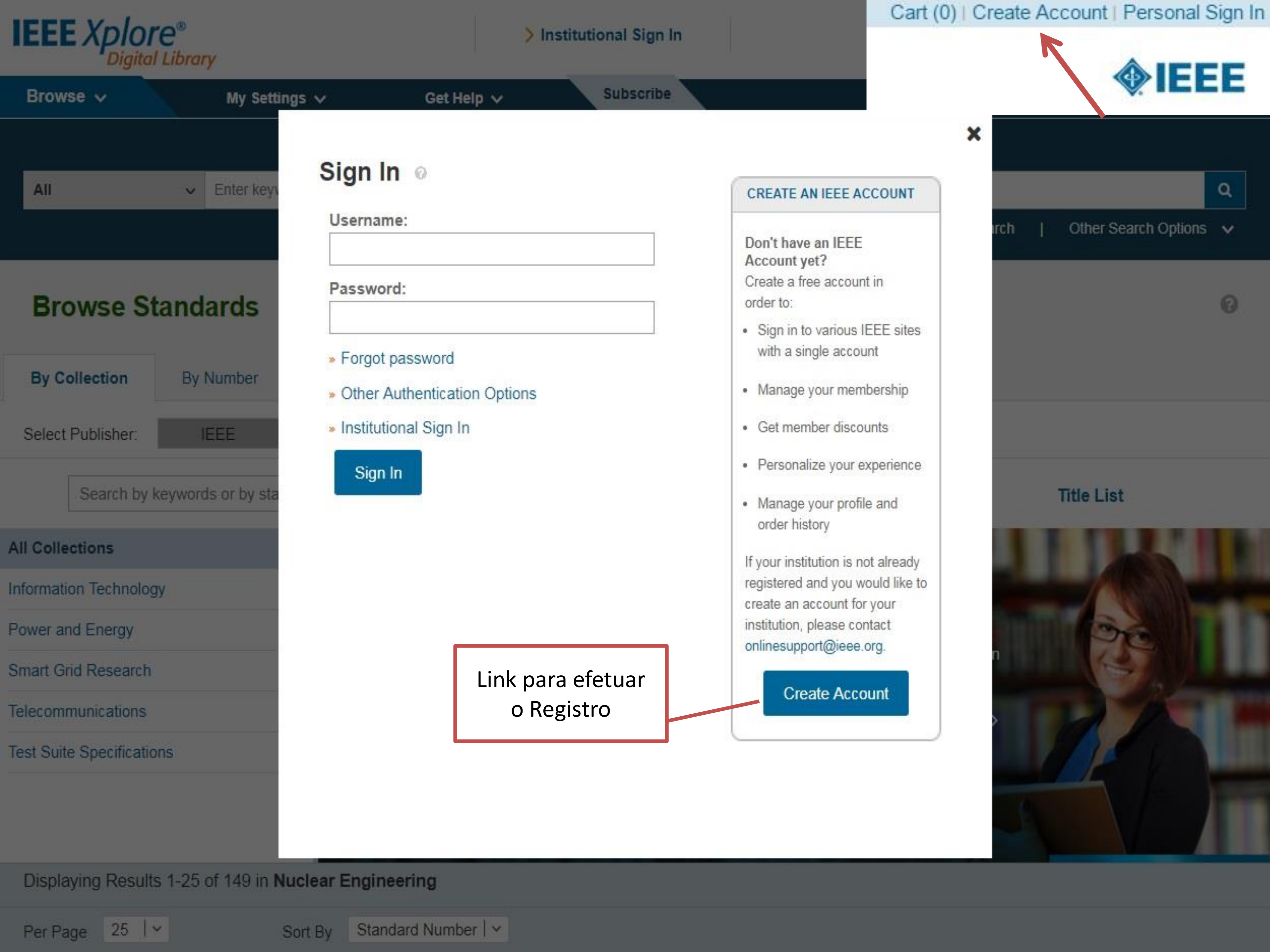
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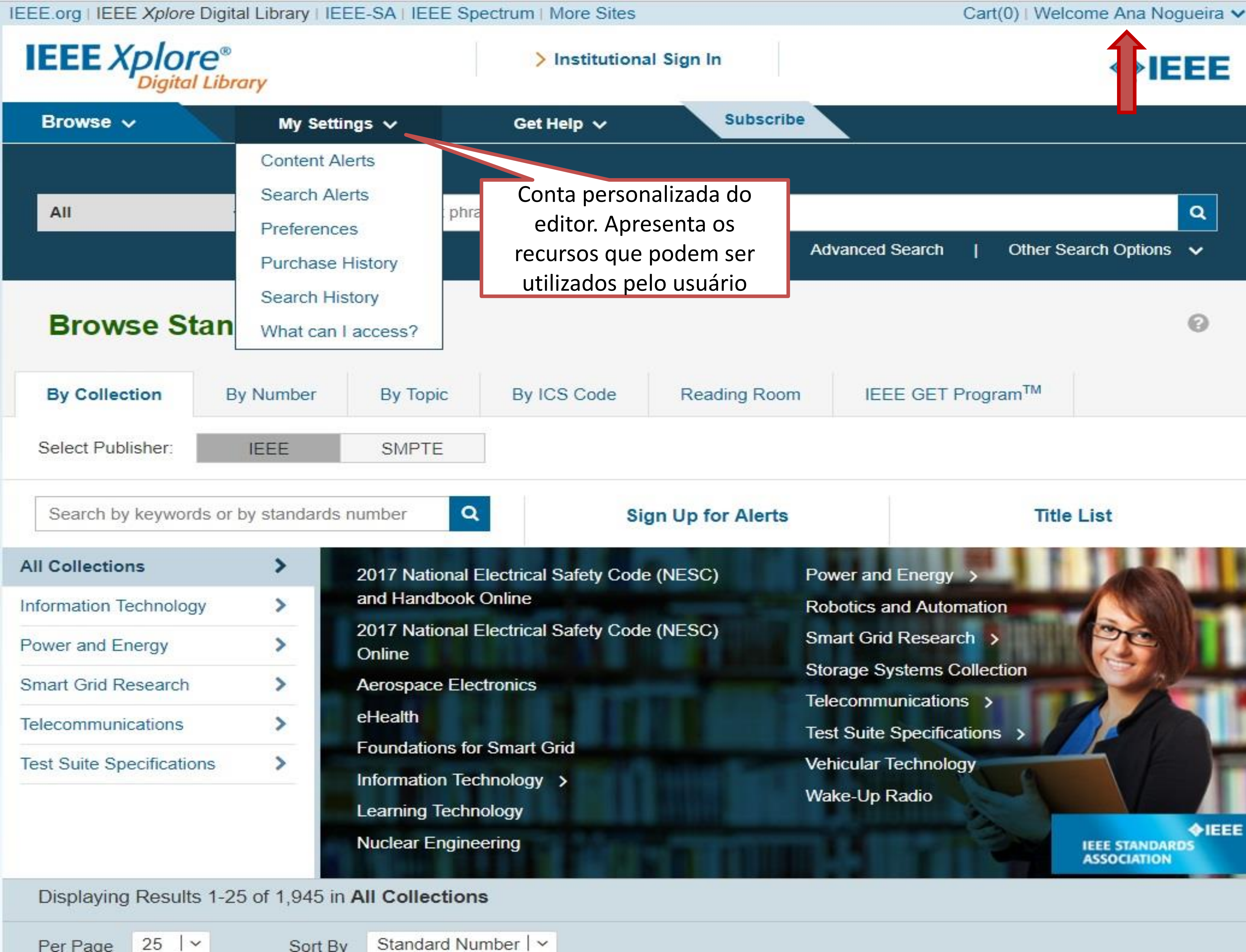

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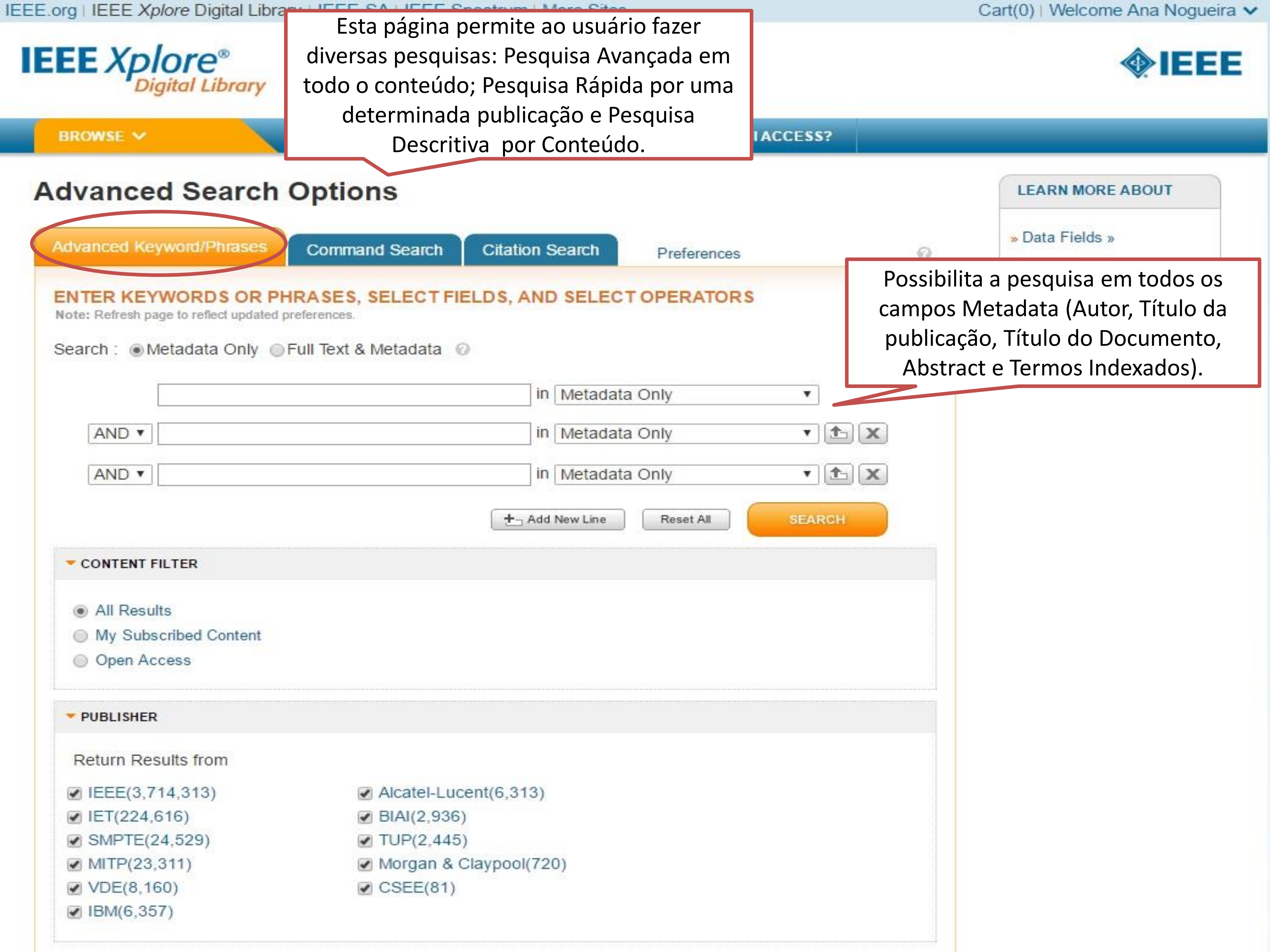

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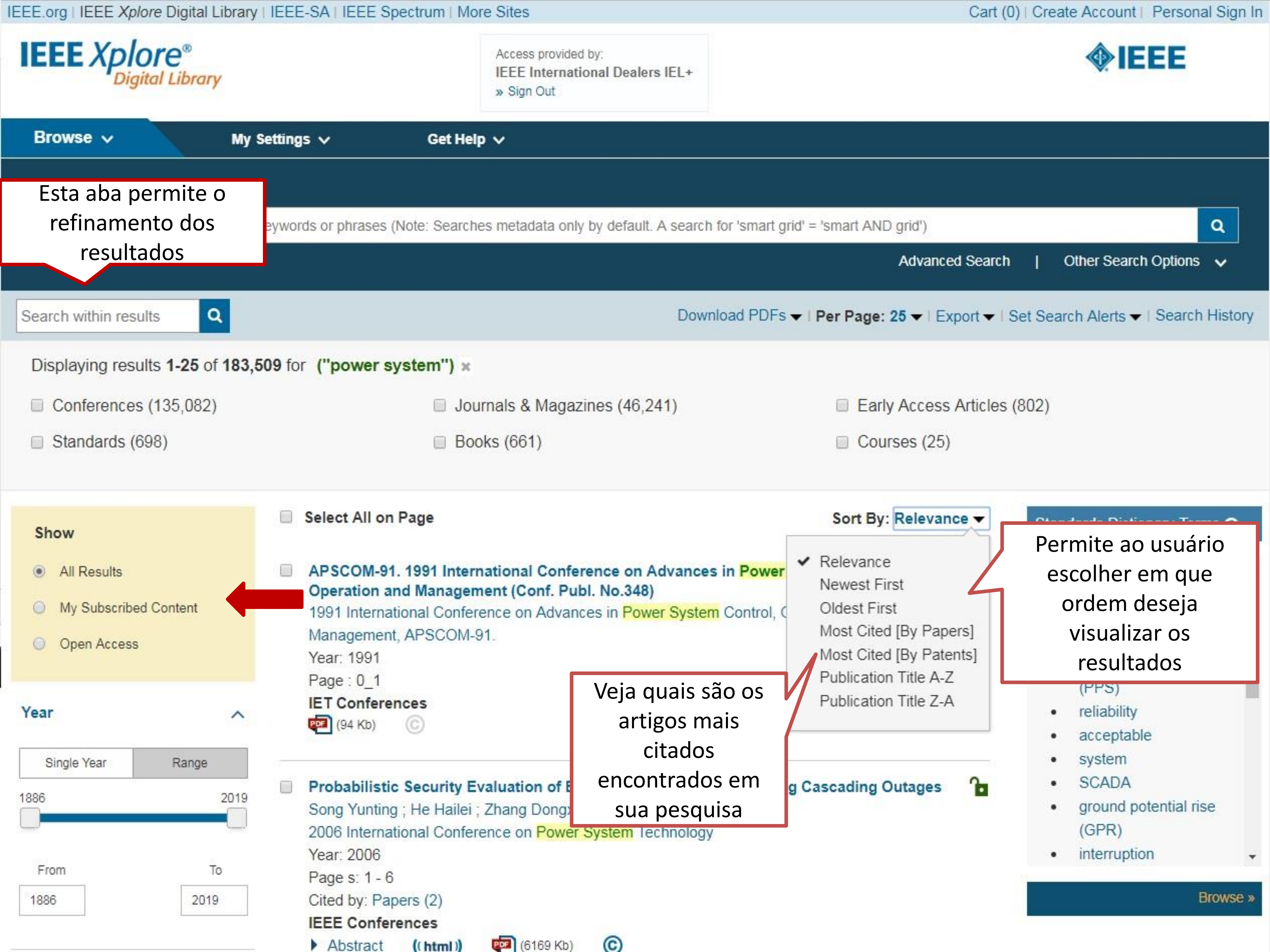
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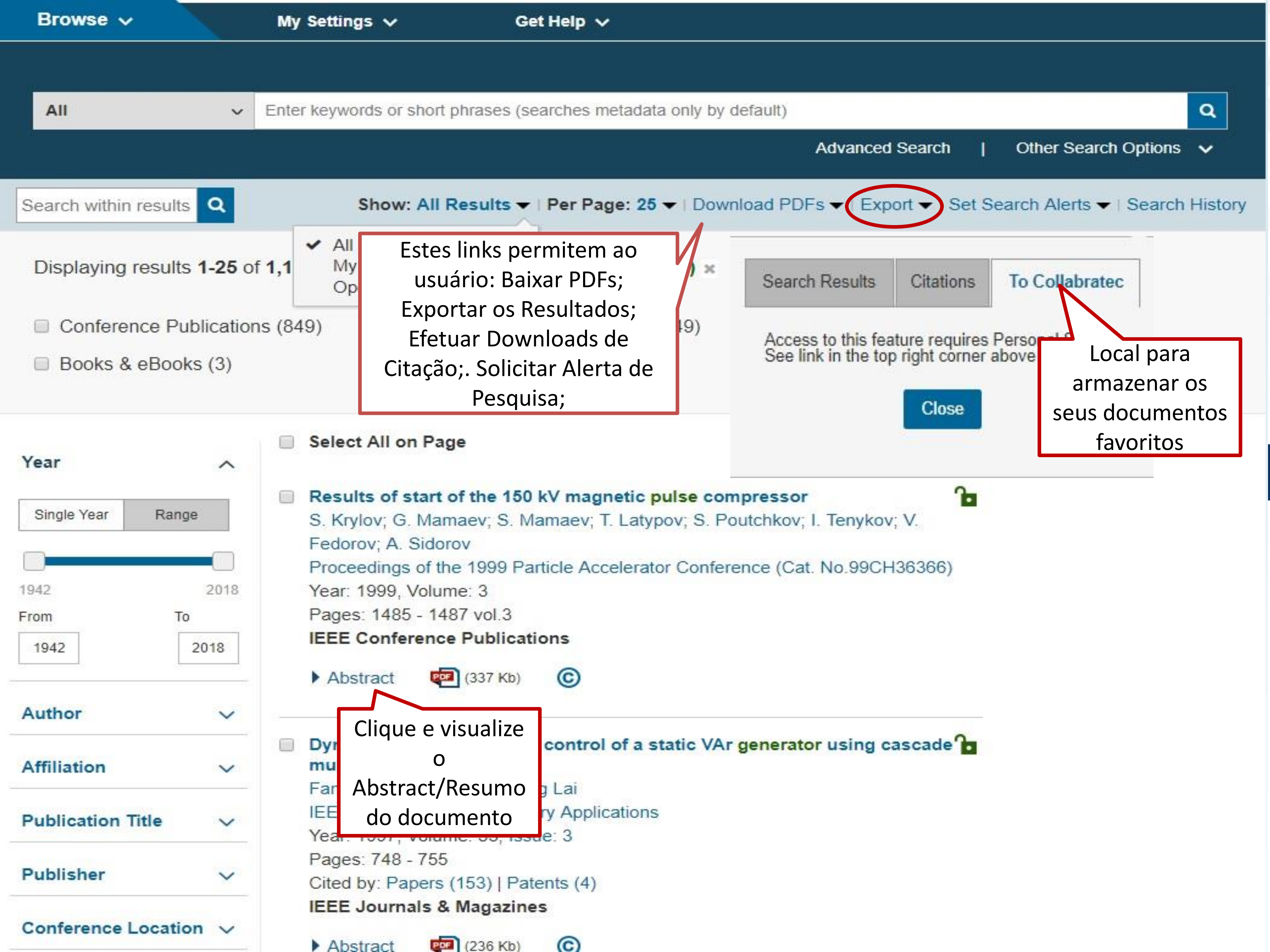
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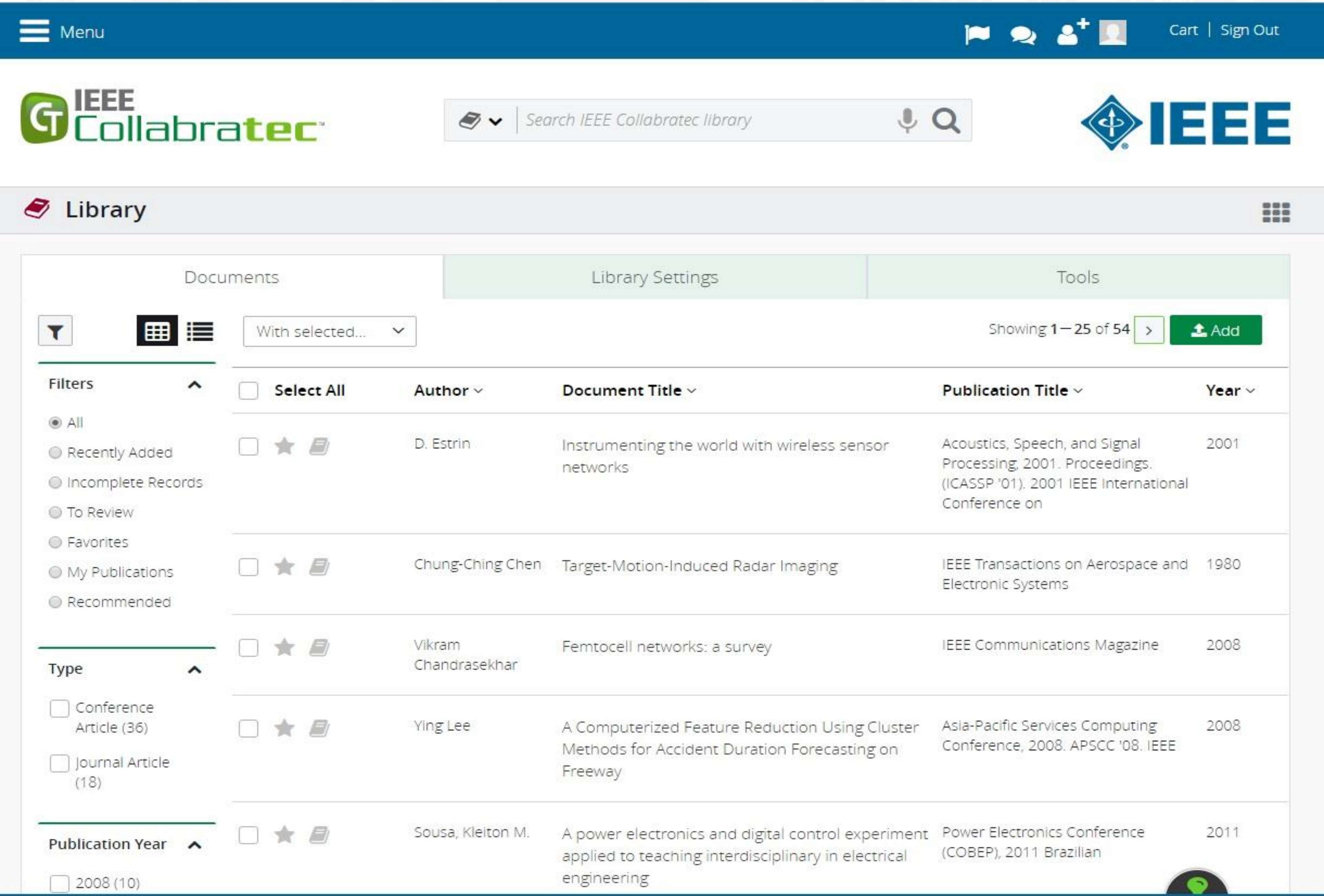

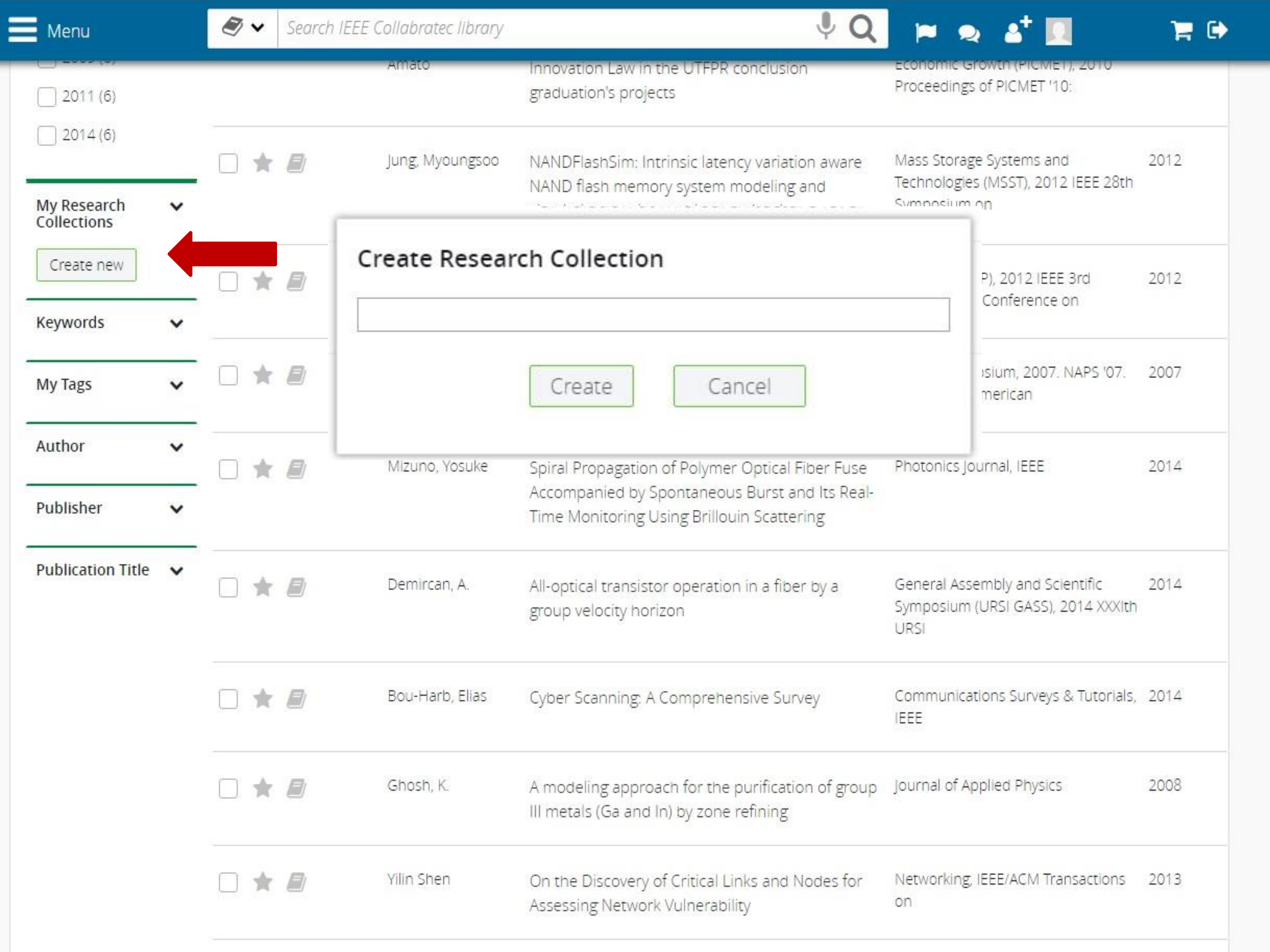
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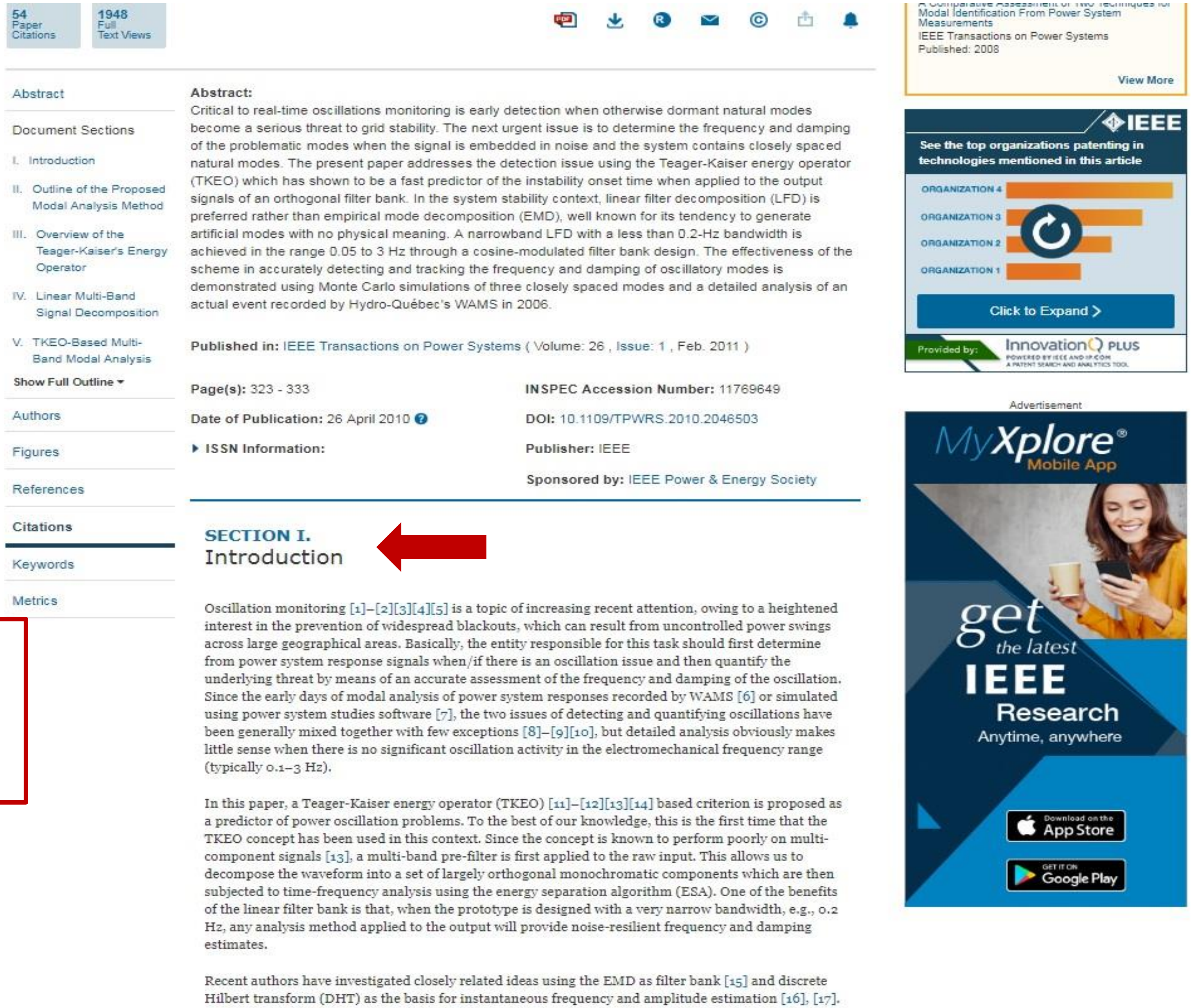

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Critical to real-time oscillations monitoring is early detection when otherwise dormant natural modes become a serious threat to grid stability. The next urgent issue is to determine the frequency and damping of the problematic modes when the signal is embedded in noise and the system contains closely spaced natural modes. The present paper addresses the detection issue using the Teager-Kaiser energy operator (TKEO) which has shown to be a fast predictor of the instability onset time when applied to the output signals of an orthogonal filter bank. In the system stability context, linear filter decomposition (LFD) is preferred rather than empirical mode decomposition (EMD), well known for its tendency to generate artificial modes with no physical meaning. A narrowband LFD with a less than 0.2-Hz bandwidth is achieved in the range 0.05 to 3 Hz through a cosine-modulated filter bank design. The effectiveness of the scheme in accurately detecting and tracking the frequency and damping of oscillatory modes is demonstrated using Monte Carlo simulations of three closely spaced modes and a detailed analysis of an actual event recorded by Hydro-Québec's WAMS in 2006.

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SECTION I.
Introduction

Oscillation monitoring [1]–[2][3][4][5] is a topic of increasing recent attention, owing to a heightened interest in the prevention of widespread blackouts, which can result from uncontrolled power swings across large geographical areas. Basically, the entity responsible for this task should first determine from power system response signals when/if there is an oscillation issue and then quantify the underlying threat by means of an accurate assessment of the frequency and damping of the oscillation. Since the early days of modal analysis of power system responses recorded by WAMS [6] or simulated using power system studies software [7], the two issues of detecting and quantifying oscillations have been generally mixed together with few exceptions [8]–[9][10], but detailed analysis obviously makes little sense when there is no significant oscillation activity in the electromechanical frequency range (typically 0.1–3 Hz).

In this paper, a Teager-Kaiser energy operator (TKEO) [11]–[12][13][14] based criterion is proposed as a predictor of power oscillation problems. To the best of our knowledge, this is the first time that the TKEO concept has been used in this context. Since the concept is known to perform poorly on multi-component signals [13], a multi-band pre-filter is first applied to the raw input. This allows us to decompose the waveform into a set of largely orthogonal monochromatic components which are then subjected to time-frequency analysis using the energy separation algorithm (ESA). One of the benefits of the linear filter bank is that, when the prototype is designed with a very narrow bandwidth, e.g., 0.2 Hz, any analysis method applied to the output will provide noise-resilient frequency and damping estimates.

Recent authors have investigated closely related ideas using the EMD as filter bank [15] and discrete Hilbert transform (DHT) as the basis for instantaneous frequency and amplitude estimation [16], [17].

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SECTION I.

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...wer is seeing ... able wind resources, higher and steadier wind speed, and r... o main types of configurations are proposed and implemente... onversion systems [2]–[5]: parallel-connected configurati... The former is already implemented in practice where the biggest challenge is very costly and bulky offshore substation required to house step-up transformers, converters, and other related components [6]. The latter is gaining more attention in the literature as the offshore substation can be eliminated, though it has not been implemented yet [6], [7].

Apart from voltage source converter (VSC) based configurations [3], [4], [8]– [10], a couple of current source converter (CSC) based configurations have also been studied in the literature. Compared with thyristor-based configurations [11], [12], which feature large footprint, dependent active and reactive power control, and susceptibility to ac network disturbance, the pulse width modulation (PWM) CSC-based ones [13], [14] features natural advantages such as simple structure, grid-friendly waveforms, controllable power factor, and reliable grid short-circuit protection. Popat *et al.* [13] proposed a series-connected configuration where PWM CSCs are installed on both generator and grid sides, whereas in [14], the generator-side PWM CSC is replaced with a modular medium-frequency transformer (MFT) based converter. Compared with the configuration in [13], the one in [14] features smaller size and weight.

One common thing for existing CSC-based series-connected configurations [13] , [14] is that they are all operating under monopolar mode leading significant challenge for system insulation. The wind generator that is farthest from the grounding point must be capable of withstanding a full transmission level that is impractical. To tackle this issue, a three-phase low-frequency high-power transformer is normally connected between the generator and the front-end converter [13]. This transformer, however, is heavy and bulky increasing burden on offshore construction because of the limited space either in the nacelle or in the tower of the wind turbine [7]. On the other hand, a modular MFT-based solution is proposed in [14]. Compared with the low-frequency transformer in [13], the modular MFT gives smaller size and weight that is particularly important for offshore construction.

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Inductive Pulsed Power Supply Consisting of Superconducting Pulsed Power Transformers With Marx Generator Methodology

Haitao Li, Yu Wang, Weirong Chen, Wenbo Luo, Zhongming Yan, and Liang Wang

***Abstract*—We have been developing an inductive pulsed power supply (PS) consisting of several superconducting pulsed power transformers with Marx generator methodology. Each of these pulsed power transformers consists of a copper secondary winding and a high-temperature superconducting primary winding. In order to obtain a high-voltage impulse, the Marx generator should be charged via the parallel connection of capacitors and discharged**

When energy transfer is required, a rapid current collapse in the primary winding is excited, and a large level of current is induced in the secondary winding. In this case, another problem occurs, i.e., the load voltage on the secondary side moves to the primary side with multiplied voltage by the winding ratio of the transformer, and as a result, it becomes difficult to open the

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