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Electric vehicle charging to support renewable energy integration in a capacity constrained electricity grid

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ABSTRACT

Digby, Nova Scotia, is a largely rural area with a wealth of renewable energy resources, principally wind and tidal. Digby's electrical load is serviced by an aging 69 kV transmission line that often operates at the export capacity limit because of a local wind energy converter (WEC) field. This study examines the potential of smart charging of electric vehicles (EVs) to achieve two objectives: (1) add load so as to increase export capacity; (2) charge EVs using renewable energy.

Multiple survey instruments were used to determine transportation energy needs and travel timing. These were used to create EV charging load timeseries based on "convenience", "time-of-day", and idealized "smart" charging. These charging scenarios were evaluated in combination with high resolution data of generation at the wind field, electrical flow through the transmission system, and electricity load.

With a 10% adoption rate of EVs, time-of-day charging increased local renewable energy usage by 20% and enables marginal WEC upgrading. Smart charging increases charging by local renewable energy by 73%. More significantly, it adds 3 MW of load when power exports face constraints, allowing enough additional renewable electricity generation capacity to fully power those vehicles.

1. Introduction

The Municipality of Digby (Fig. 1, left) is embarking on an ambitious strategy to alter its energy consumption and production, for greater utilization of locally produced renewable energy. Transportation represents a major energy end-user, totalling 38% of all energy used in Nova Scotia [1]. This energy comes almost entirely in the form of gasoline and diesel. While Canada has significant fossil fuel resources, there is no petroleum production in Nova Scotia, so transportation fuels represent a significant economic trade deficit for the region. In contrast, Nova Scotia in general, and the Digby area in particular, have superb renewable energy resources consisting principally of wind and tidal flows [2,3]. Electric vehicles (EVs) which have greatly increased efficiency compared with internal combustion engines, thus represent an opportunity to not only vastly reduce energy consumption for transportation, but also to transition from imported fossil fuels to locally produced renewable energy.

The electrical transmission system of the area is shown in Fig. 1 (right). It consists of 69 kV lines servicing the Town of Digby via Conway Substation. Other 69 kV lines connect nearby communities and collect from small hydroelectric facilities inland. In 2010 a 30 MW wind energy converter (WEC) field, consisting of twenty GE 1.5 MW units, was commissioned on the Digby Neck, causing Digby to become a net exporter of electricity. This 30 MW wind field was sized to meet summertime transmission export limits when local loads are at their minimum. As a consequence, further development of renewable electricity generation is not permitted, absent one of three conditions: Either (1) the transmission system is upgraded to increase the export capacity, (2) renewable generation must be curtailed when transmission limits are reached, or (3) electrical load must be added locally, so that the additional power produced can be used locally and not contribute to overloading of the transmission system.

Option 1 is not being considered by the provincial electricity system manager in short or long term planning because it would be prohibitively expensive. Option 2, while not presently supported by the grid manager, is a reactive approach that is undesirable due to the loss in renewable energy caused by curtailment. It is under the premise of Option 3 that this study is conducted. The addition of EVs adds load to the local electricity network. By evaluating the time-dependent load of charging EVs and their interaction with existing loads and generation, this study will quantify the influence of EVs on the electricity grid for a local region, and the use of renewable electricity generation for powering those EVs.

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Nomenclature

EV	electric vehicle	WEC	wind energy converter (wind turbine)
TOD	time of day; electric rates that vary ($/kW h) on a fixed schedule		

The use of energy storage and dispatchable load to manage variations in renewable energy output is a problem of nearly universal concern in utility management as non-dispatchable renewable energy sources become a significant contributor to total energy and grid instability [4–7]. Applying the possible grid management benefits of EV charging to achieve a specific grid management objective is of great interest to governments and utilities [8,9], so this case study, which benefits from well-defined grid constraints and precise grid loading data, may be of particular interest to policy makers.

The interaction of EVs that plug into the electrical system, and the electrical system itself rely entirely on an accurate understanding of when EVs are used, how much energy they consume when they are used, and when they are returned to a location where they can plug in and charge. The significance of the driving patterns is made doubly important when one considers three possible effects of EVs on the energy system [10]. One possibility is an undesirable evening peak in load that could occur if charging rates and timing are unconstrained, referred to here as "convenience charging". The second is to respond to "time of day" (TOD) electricity rates with a charge timer, in which case an evening load peak is avoided and loads overnight are increased, but no more finely tailored benefits can be realized [11,12]. The third possibility is "smart charging", which is managed by grid operator intelligence and real-time control, in which EV charging loads become a controllable resource providing valuable grid services.

Any charging strategies that are successful in reducing or controlling the export transmission loads could correspondingly permit increased local generation capacity. General Electric (GE), the manufacturer of the WECs in use at the wind field have developed a control software update titled WindBOOST, which increases the maximum power output by 10%, from 1.5 MW to 1.65 MW. This modification could be implemented at negligible cost, and would increase WEC field power capability to 33 MW, and annual average energy production by roughly 4% [13,14]. As an objective, this study investigates the potential of adding controlled EV charging, thus allowing the WindBOOST upgrade, with the intent that the added energy production would be sufficient to provide the necessary energy to charge the EVs, making them a net benefit to Nova Scotia's grid.

2. Data sources/research methods

To conduct a thorough investigation of EVs and their impacts upon the electrical grid requires an understanding of the present transportation fleet in Digby with respect to both vehicle populations and vehicle use. Specifically, to understand the energy requirements of vehicles, it is necessary to know (1) how many vehicles of various types are in use in the area, (2) how much energy these vehicles use each day (how far they drive and how much fuel is consumed to do so), and (3) during what period of the day, and particularly when at the end of the working day, they are parked, indicating when vehicles would plug into the electricity grid. With those data and an assumed adoption rate of EVs, grid impacts can be estimated.

The following subsections describe the regions of analysis, the data sources related to vehicle populations in the area, the survey tools used to gather vehicle use information, and the data available on grid loading and renewable electricity generation.

2.1. Vehicle populations

The total vehicle population in Digby comes from Provincial vehicle registration data [15], however, the population served by

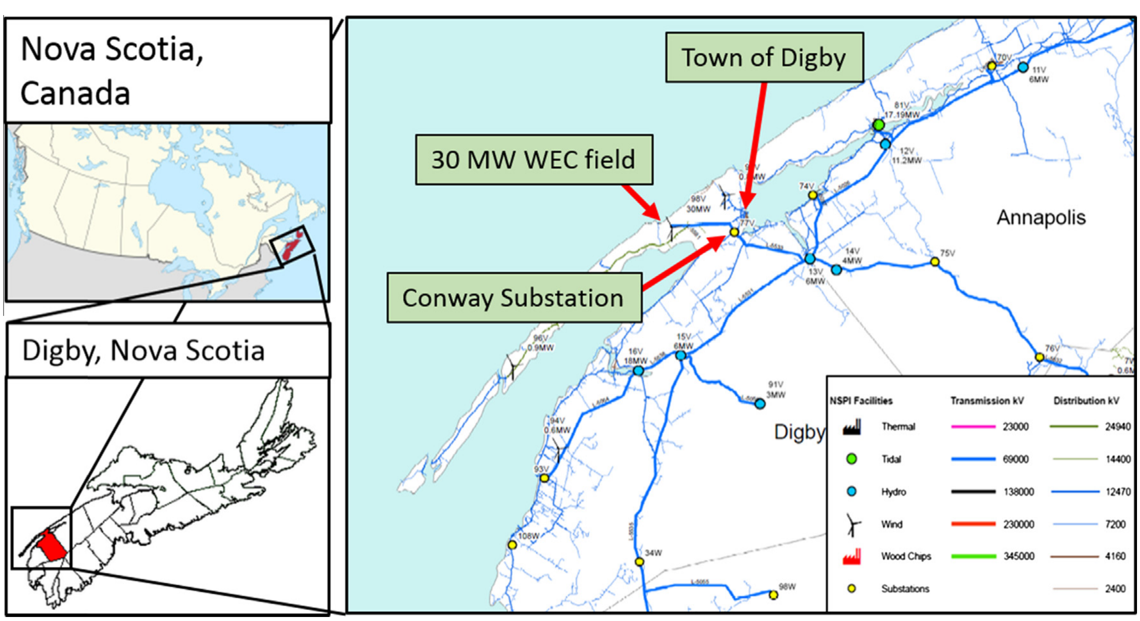

Fig. 1. Location of Digby (left) and transmission and distribution maps (right).