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Synergies of Wind Turbine control techniques

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ABSTRACT

During the next decades, the market for Small-Scale Wind Turbines (SSWT) is expected to grow, due to a shift in micro-generation and current trends in distributed energy resources. Meanwhile in the last two decades, there were significant developments in control techniques for Large-Scale Wind Turbines (LSWT). Nonetheless, there exist synergies in Wind Turbine (WT) technologies from small to large scale. The reduction of WTs' operation and maintenance costs directly correlate to technical and economic matrices, which is crucial to the success of the wind energy industry. The aim of this paper is to compare WT control techniques from small to large scales levels, identifying common challenges and developments to achieve intelligent control algorithms at the small-to-medium scale levels. Therefore, the potential impact of increasing the competitiveness of wind energy in urban and suburban areas is explored and discussed through affordable and feasible levelised wind electricity costs.

Contents

1. Introduction

In the last two decades, the wind energy industry has significantly developed and technology matured. This development was mainly due to the international policies from directives specifically related to climate change as well as the fossil fuel electricity fluctuating prices, which has stimulated technology advances in the sector that managed to attract novel technologies and systems, in design, control as well as wider range of sizes.

The wind energy resource is one of the most promising, mostly observed and adopted worldwide. This paper focuses on a comprehensive literature survey on the development of Wind Turbines (WT) control techniques including new schemes in energy production, optimisation of design and operation, separate fields of control, stand-alone units and grid integration.

There is a clear distinction on onshore and offshore Large-Scale Wind Turbines (LSWTs) due to a vast augmentation of the market. The vast research in this area aim an optimal solution at all the stages from the construction of the plant, operation peculiarities, predictions, and up to the power outputs and maintenance costs. However, there is little literature on Small-Scale Wind Turbines (SSWTs) control techniques. In fact, most literature on SSWTs focuses on new design approaches and aerodynamic investigations for the vertical axis wind turbines (VAWT) which are deployed for the pilot case studies. However, in practice most SSWTs are still horizontal axis wind turbines (HAWT). On the other hand, forecasted developments of VAWTs suggest the electricity production may increase by tenfold as VAWTs become

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economic and have lesser footprint [1]. Inevitably, a very clear definition of SSWT should follow but regrettably is still not quite properly expressed [2]. Basically, SSWTs are associated with WTs rotors of less than 100 cm, capable of extracting the power up to 50 kW [3,4]. Small-to-medium scale WTs encompass units up to 350 kW depending on the country adoption of EU standards.

The aim of this paper is to compare WT control techniques from small to large scales levels, identifying common challenges and developments to achieve intelligent control algorithms at the small-to-medium scale levels. Therefore, the potential impact of increasing the competitiveness of wind energy in urban and suburban areas is explored and discussed through affordable and feasible levelised wind electricity costs.

The paper is structured as follows: after a brief introduction, Section 2 highlights the major system level challenges for the SSWT and Section 3 describes the control techniques identifying various limitations and techniques for LSWT. Then, Section 4 identifies the constraints and applications for SSWT. Finally, Section 5 draws the general discussion and conclusions on this comprehensive review.

2. Small scale wind turbine (SSWT) challenges

Onshore WTs applications in urban or suburban areas are synonymous with low wind speeds of up to 5 m/s, which are usually neglected in the field of research [5]. These WTs are distinct and more complex to control from LSWT operating at higher wind speeds due to the variability in time and turbulences. In fact, SSWTs may be less attractive to the wind energy industry due to their smaller scale in power generation and increased control techniques complexity.

On the other hand, a new model of SSWT proposed with an inverse design and optimisation tool from Blade Element momentum theory, found to be efficient even at very modest wind speeds [3]. Even at gust conditions and unpredictable features of the wind, a SSWT using untypical generator with a changeable rotational speed was able to produce greater amount of energy than under normal predictable conditions [6].

The future electricity grids in smart cities and communities make SSWT attractive in both the developing and developed energy markets. Smart grid aggregates the distributed energy resources, at the same time transmit, and distribute energy to the consumer in the vicinity of the end user site using intelligent systems and virtual conception [7–9]. An appropriate coordination of decentralised power sources matches the flexibility of all the grid participants and reduce the imbalance of energy. However, as these systems and grids are on a small scale, they do not yet show a considerable impact economically or environmentally. Economic feasibility of the systems is still under studies and show the prospects of hybrid systems more suitable to the citizens [10] and often not very profitable [11]. Thereby the idea of smart cities and communities emerge independence on monopolist but urge the society to think systematically and act with solidarity.

SSWTs have also exhibited lower amount of noise during operation [12] than one arising from aerodynamics and vortices induced by the wake of LSWT. The lower environment disturbances [13] and lower costs of building and maintaining per unit were clearly revealed in various SSWT investigations but regrettably there have been issues with low efficiency and lack of reliability in power generation. These are the main reasons why SSWT are so poorly supported with financial schemes [2].

The major primary problem of SSWTs is the wind speed operation range, typically between 10 and 13 m/s [3], which is too high for urban areas. Other concerns are the cost efficiency needed to overcome inputs [14] and record efficiency as expected [4,15,16]. The major challenge though remains to be the energy generation prediction and control techniques [16–22]. These challenges and concerns makes these systems more expensive than LSWT and therefore individualised in their urban application site due to different and uneven manner of the flow patterns and adaptation [23–26]. Poor aerodynamics of SSWT leads to the extraordinary attempts to make the wind system profitable and reliable. Moreover, social acceptance is not an exception judging the position of SSWT in the market and technical development thus leading to ambiguity rather that to in-situ investigations.

3. WT control and developments

LSWTs control techniques are focused on three main criteria: (i) power optimisation [27–29], (ii) blade pitch angle adjustment for the varying wind speeds and wind directions [30–32] and (iii) generator torque to stabilise technical parts of the WT [29,33–35]. Recent trends to encompass the components of mechanical, aerodynamic, social and economic fields make the control techniques multi input and multi output (MIMO) [36]. The integration of generated power into the electricity grid is an overall challenge, especially for the SSWTs [17,37–40]. LSWT farms are now required to transmit aggregated power as a single power unit [41]. The optimal control turns not only to satisfy some technical parameters, minimisation or maximisation of diverse characteristic measures but also to ensure better predictability, reliability, operation efficiency, network tasks – load, appropriate quality of energy and integration. Generally, the rated power regimes of WT at their rated velocity values are multi-objective, of several closed loops with the feedback that enable the systems' control flexibility and process minimisation, maximisation or required damping [42]. In addition, open loop systems deal with linearity and do not assess appropriate stability during wind speed variations [43].

Control systems are developing together with the WT development, improvements and data analysis progress [1,36,42–45]. Due to the great differences among WT systems, a classical and universal model of the performances is hardly achievable and improper, especially in cases of fluctuating wind speeds conditions and nonconventional applications. In highly turbulent flows or complicated environment with uncontrollable sudden alternating wind speeds and turbulence intensity, it is complex and difficult to assess [24]. Any abrupt behaviour on the operation performances leads to the faults and breakups. Therefore, current control techniques can be barely capable to react simultaneously [46]. On the other hand, the static and dynamic parameters are implemented into the process, by subtracting or adding the appropriate subparts essential for the aim to pursue. Different subsystems integrated for higher control accuracy make the models very specific [37,47,48]. However, advanced control solutions make WTs flexible enough to overcome uneven loads, become cost-effective, long lasting, capable to maximise resource capture and increase efficiency [15,49,50]. Indeed, it is still not managed perfectly and the field for systematic optimisation involving a variety of impacts and phenomenon is open to be investigated in detail [51]. The multi-criteria analysis, multi-level approaches and weighting indices helps here to fix an appropriate output [15,27,49–54].

A wide range of WT control techniques exist, from the physical based to unconventional, from methods with non-controllable parameters to nonparametric. Mathematical and computational data mining algorithms give the optimal solutions where conventional theoretical basis is incapable to obtain. These techniques for LSWTs are summarised in Table 1. Eventually all of them minimise the wind electricity cost. Most of the techniques are single or bi-objective. However, sophisticated multi-objectives algorithms also