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Synchronization of a single-phase wind energy generator with the low-voltage utility grid

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Abstract. This paper presents a new circuit topology of a phase-locked loop that can be used for synchronising a single-phase wind turbine generator (WTG) with the low voltage utility grid. The circuit is based on the time-delay digital tanlock loop (TDTL) architecture and was modelled and simulated using Simulink/MATLAB. The results presented demonstrate the ability of the circuit not only to synchronise a WTG with the grid, but also to re-gain synchronization following a sudden disturbance in the grid voltage. The simulated disturbances included a ramp and a multi-step change in the phase of the grid voltage waveform.

Key words

Wind-turbine generator, renewable energy, grid synchronization, time-delay digital tanlock loop.

1. Introduction

Recent years have seen interest in renewable energy utilization increasing at a record rate [1-2]. Due to the intermittent nature of renewable energy sources (RES), its utilization has, mainly, taken one of two forms: using a standalone system in which the ac load is connected to a "standalone" inverter energised from a battery bank, or by integrating the renewable energy into the low voltage grid using a "grid-tie" inverter [3,4]. However, connecting a renewable energy (RE) generator such as a wind turbine generator (WTG) to the grid may induce unwanted effects on the grid voltage such as harmonic distortion. In order to regulate the connection and integration of an RE generator with the grid, certain regulations have been put forward by regulatory bodies such as the IEC (International Electrotechnical Commission) and the IEEE [5,6]. Prior to connecting an RE generator, or any generator for that matter, the generator voltage must be synchronised with the grid voltage. To achieve such synchronization, circuits based on the implementation of some form of the ubiquitous phase-locked loop technique have been reported in the literature [7-9]. Generally, these are analogue circuits and therefore, their working life and functionality are fairly dependent upon component tolerances and aging. In this paper, a new digital circuit topology for synchronising a single-phase wind turbine generator with the grid is presented. The circuit which is based on the time delay digital tanlock loop (TDTL) [10,11] not only synchronises a WTG to the grid, but also re-establishes synchronization whenever it is lost such as after a sudden perturbation in the phase of the grid voltage. Essentially, the circuit consists of two TDTL loops as depicted in Fig. 1. The upper loop is a second order loop through which synchronization is achieved and is used to drive the lower first order TDTL loop. Therefore, the system will be referred to as TDTL with dual input (TDTL-DI). The lower arctan phase detector produces an error signal that is proportional to the phase difference between the DCO (digital controlled oscillator) output and the grid voltage. This error is corrected by the upper loop.
Mathematical analysis and modelling of the proposed circuit along with results of its testing are presented.

2. System Analysis

A continuous sinusoidal signal $y(t)$ with a frequency offset

$$\Delta\omega = (\omega - \omega_o)$$

is received by the proposed design. This is also translated as a phase shift, from the free running frequency $\omega_o\ (rad/s)$ of the DCO as follows

$$y(t) = A\sin\left[\omega_o t + \theta(t)\right] \qquad (1)$$

where A is the input signal amplitude and