EXPERIENCE WITH ACCUMULATED PHASE ANGLE DRIFT MEASUREMENT FOR ISLANDING DETECTION

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ABSTRACT

Distributed generation is increasingly playing a major role in electricity supply systems as recognition is made of its low carbon credentials. However, the integration of these units at distribution voltages is a major challenge for utilities. One particular issue is that generators may, unintentionally, continue to supply local demand when areas of the network are isolated from the main system. Reliably detecting this condition is regarded by many as an ongoing challenge as existing methods are not entirely satisfactory. This paper proposes a novel method based on accumulated phase angle drift that provides inherently enhanced stability without unduly sacrificing sensitivity. It is passive and thus requires no additional invasive hardware. Transient simulations have been used previously to demonstrate its performance [1]. The current paper presents further validation of the PAD method performance resulting from the field trial of relays connected on the 38kV network in Ireland, Scottish Power 33kV network in North Wales and an on-going laboratory trial at the University of Strathclyde (UoS).

Keywords: power system relaying, loss of grid, digital transient simulation, distributed generation.

1 INTRODUCTION

The connection of generation at distribution voltages is seen as one of the most important challenges facing modern electricity supply systems. These units offer the potential to take advantage of local renewable or sustainable energy sources, whilst avoiding the high carbon emissions and losses associated with large fossil fuel thermal stations and long distance transmission respectively. There is strong consensus that many issues need to be tackled before distributed generation can play a safe, reliable and profitable role in modern electricity supply systems.

A specific area of concern for utilities is that distributed generation (DG) may continue to supply local demand when areas of the network are isolated from the main system [2]. This is a particularly undesirable condition and therefore protection is required for its detection and the subsequent tripping of DG. Although many protection methods have been developed for this task, concern still exists with regard to their performance in terms of the highly interrelated criteria of sensitivity and stability [3]. This paper proposes the use of a method based on accumulated phase angle drift that provides inherently enhanced stability without unduly sacrificing sensitivity. This method continues with the prevailing practice of using only passive techniques and thus requires no additional invasive hardware.

2 ACCUMULATED PHASE ANGLE DRIFT (PAD)

The proposed method is dependent on only passive principles with a tripping threshold being applied to an accumulated phase angle drift calculated from measured frequency values.

The method is based on the threshold comparison of an accumulated phase angle drift derived from the difference between the current measured local frequency and that estimated using historical data (this being reflective of the current grid frequency).

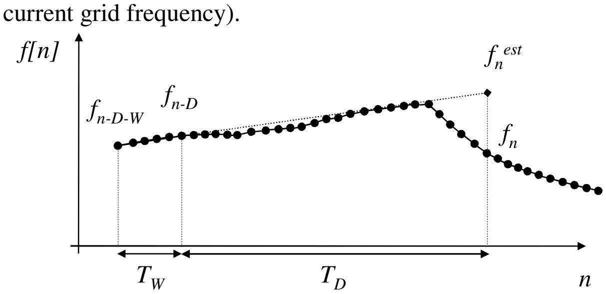

Figure 1: An illustration of frequency estimation using linear extrapolation based on historical data.

When a true loss of grid event occurs, the measured frequency will deviate from its nominal rated value and thus a difference will exist with respect to the estimated grid value. This difference in frequency will lead to changes in the phase angle that will increase (drift) with time. The nature of this increase is complex and is dependent upon a range of factors, including: generator inertia, initial power imbalance and the parameters of the method used for frequency estimation.

5. TRANSIENT PERFORMANCE ANALYSIS

The transient performance of the proposed method has been assessed using Real Time Digital Simulation (RTDS) simulating a combination of idealized disturbances and full islanding simulations using rotating machine models.

The dynamic response of a synchronous machine to a loss of grid connection is primarily determined by the inertia constant of the machine. The controller parameters although important do not significantly impact on the dynamic response in the first few hundred milliseconds of the transient. The behaviour of a DFIG based generator depends mostly on the control e.g. a Phase-Locked Loop (PLL) controller. Shortly after disconnection from the grid and the loss of the reference signal the controller becomes unstable. Identification of the islanding event is therefore relatively easy in such cases [4]. For this reason only synchronous machines were tested in the simulations.

5.1 Simulation Model

Two main network case studies have been used: the first scenario tests the operation of relays protecting a synchronous generator connected to a 33kV network, and the second scenario tests the operation of relays protecting a synchronous generator connected to a 11kV network. These models are simplified versions of the full network supplied by a UK DNO with appropriate aggregations made to reduce their complexity where necessary. Each scenario consists of a grid source, simplified network, point of isolation, local trapped load and generator (including a step-up transformer where appropriate). In the model, for simplicity, the control is using P+V. The important controller for loss of grid is that of the governor and this is modelled appropriately. For the AVR, basic voltage control is enabled which is satisfactory (provided that the resultant power factor is within normal acceptable bounds).

A single line diagram for the 11kV network model and fault locations is shown in Figure 2.

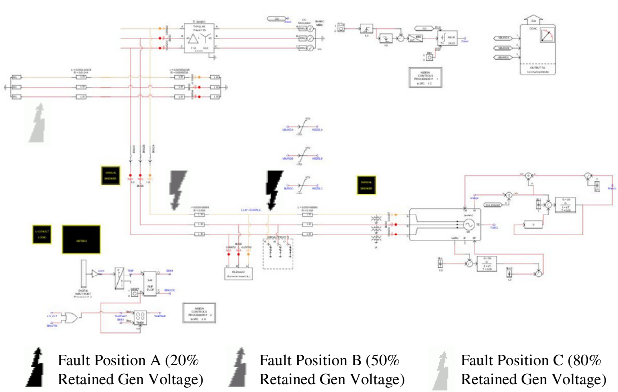

Figure 2: 11kV network model and fault locations.

5.3 RTDS Sensitivity Tests

Loss of grid test cases using a synchronous machine at 0%, 2.5%, 5% and 10% power imbalance were carried out to check the sensitivity of the protection. Figure 3 shows the response of PAD with a 2.5% real power imbalance between the pre-islanding output and captured demand. The algorithm can detect the loss of grid in all test cases, except 0% imbalance. The trip time increases linearly with PAD angle setting. To assess the performance a 500ms trip time was used to determine the maximum settings for sensitivity. Figure 4 shows the maximum PAD settings to detect various power imbalances for the 33kV test network. To detect all imbalances a suitable setting of 10° is sufficient for both test networks. This setting can be further increased if the operating time criterion is relaxed.

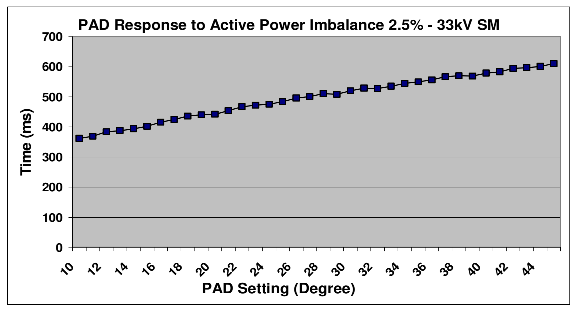

Figure 3:33kV SM Sensitivity Active Power Imbalance 2.5%

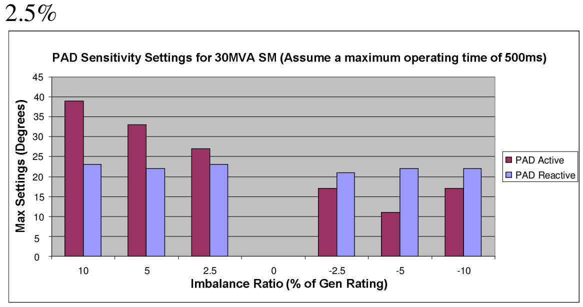

Figure 4: 33kV SM Maximum Sensitivity Setting for PAD

5.5 RTDS Stability Tests for Network Fault Scenarios

To test the stability, test cases were created with various fault types causing voltages to be reduced (retained voltage) to 20%, 50% and 80%. For the 33kV network model the protection is stable for all fault types except close-up three-phase faults. The trip time also increases in an approximately linear function with setting values. For the 11kV network model the protection is stable for all fault types if the angle setting is set at or above 10°. The responses to a remote three-phase network fault, which is the worst case for stability, at 20%, 50% and 80% retained voltages are shown in Figure 5. The minimum PAD setting to achieve stability for a 1/2/3 phase fault is 8° for the 11kV network model.

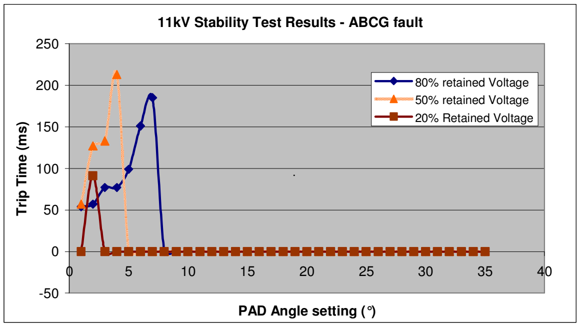

Figure 5: 11kV SM Stability (Retained Voltage 80%, Three-phase fault).

5.6 Performance assessment

The results show that the relay is sensitive to a very small (2.5% on the generator base) mismatch in active power with a setting in the region of 10° with a trip time <500ms. With the same setting the protection is stable for the vast majority of simulated fault scenarios with the exclusion of the 33kV system three phase fault with a retained voltage of 20%V_n. Therefore, significant stability gains are evident while a high level of sensitivity is preserved.

6 SITE TRIALS

A protection relay with the PAD algorithm has been connected on the 38kV network at the interface to a 25MW windfarm in Ireland since August 2011, see Figure 6. A PAD relay has also been connected to the 3 phase low voltage supply in the laboratory at the University of Strathclyde (UoS) since October 2009. A PAD relay has also been connected since February 2012 on the Scottish Power network to a 33kV circuit at Rhyl substation which is connected to a 60 MW offshore wind farm.

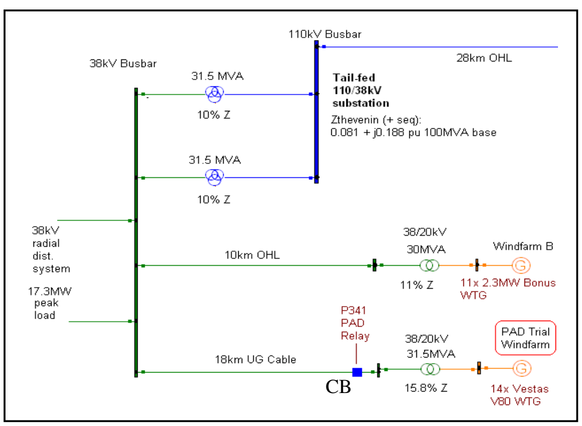

Figure 6: PAD relay connection to a windfarm in Ireland

All the trial relays are set up to trigger the disturbance recorder from the PAD protection with a sensitive setting of 5° to capture power system events.

6.1 Disturbance Record (DR) Analysis

An analysis of a few records from the site trials are used to illustrate the real life performance of the relay, to achieve best settings and optimally tune the algorithm parameters.

6.1.1. Record 1

Figure 7 shows a DR from the Ireland trial relay on 10 September 2011. Initially the 38kV cable was energised from the system down as far as the windfarm. The breaker was then opened at one end of the 38kV cable, disconnecting the windfarm from the system causing a loss of voltage seen in the DR.

A transformer magnetising current of 5A was measured by the relay before the CB was opened indicating the wind farm generators were not outputting power at this stage.

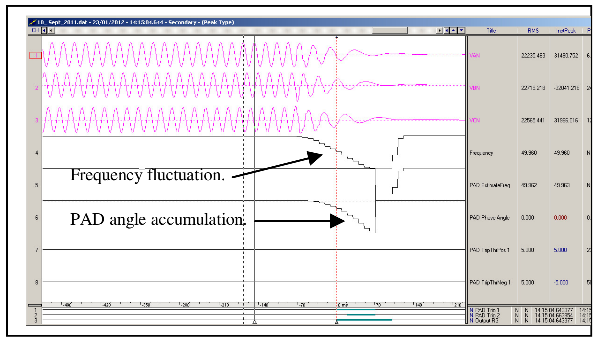

Figure 7: Transformer disconnection 10 Sept 2011, 07.39.01.000 at windfarm in Ireland

The DR shows that the frequency is dropping from 49.96Hz before the CB is opened to 49.323Hz at the PAD trip and then reduces to 47.942Hz as the CB opens. As the transformer de-energises the voltage drops below the relay frequency tracking level of 10V secondary at which point the relay uses its default setting of 50Hz and the PAD resets.

The PAD picks up momentarily when the actual frequency and estimated frequency differ for a short time as the transformer de-energises with the maximum PAD angle being -32.25°. The grid CB operation can be considered as a loss of grid condition so in this case the PAD operation is desirable. The PAD angle is accumulating correctly until the voltage decays to a low level demonstrating good sensitivity of the PAD protection to a genuine loss of grid incident.

6.1.2. Record 2

Figure 8 shows a voltage disturbance DR from the relay at the UoS on 19 May 2010. The frequency is 49.965Hz at the start of the record and VA = 265V, VB = 269V and VC is 269V rms.

Initially, there is a large voltage dip in the B phase to 32V rms (12%) and a smaller dip in A and B phases to 178V rms (67%) and 157Vrms (58%) respectively for approximately 32 cycles. The residual voltage is very low before and during this disturbance. Later in the record there is a voltage dip in all 3 phases to 34V (13%) / 34V (13%) /

38V (14%) rms respectively.

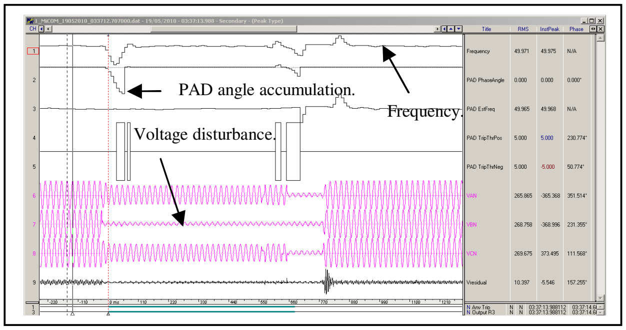

Figure 8: Voltage fluctuation 19 May 2010, 03.37.12.707 at University of Strathclyde

There are some small frequency fluctuations caused by the distortion in the voltage waveform as the voltages change. The largest frequency variation is from 49.965Hz to 49.69Hz during the first voltage dip. The PAD accumulates for the first frequency fluctuation to a maximum value of -6.364° and -1.5° for the second frequency fluctuation.

The voltage disturbance may be due to a fault in one phase with a fuse being blown or some static load switching. The single phase fault/switching may have been on the HV side of the delta-star transformer as the fault is visible in all phases and the residual voltage is low as the delta winding would block the zero sequence component. The PAD would be stable for this incident with a setting of 10°.

6.1.3. Record 3

Figure 9 shows a frequency fluctuation recorded from the relay in the Rhyl site trial on 28 September 2012.

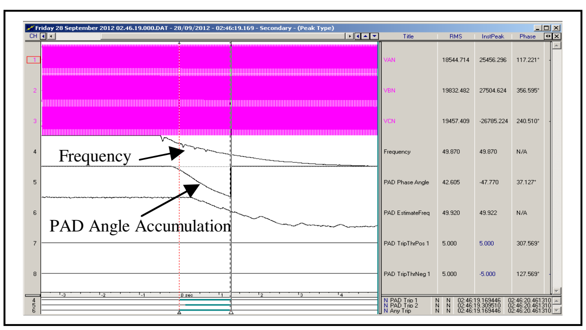

Figure 9: Frequency fluctuation 28 September 2012, 02.45.42.000 at Rhyl

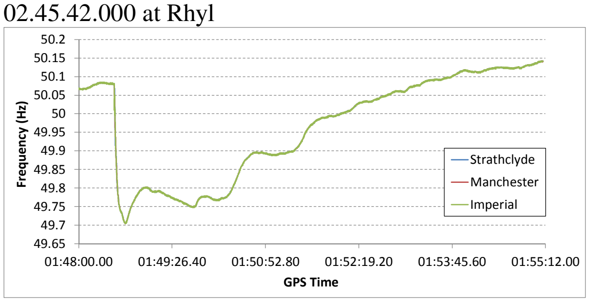

Figure 10: PMU frequency DRs on 28 Sept. 2012

The DR shows the frequency initally at 50.08Hz and then reduces by 0.337Hz to a minimum of 49.743Hz at the end of the DR in approx 5.483s (average df/dt over this period is 0.062Hz/s). The PAD phase angle accumulates down to -54.77° before resetting.

This frequency disturbance was caused by a bipole tripping incidents on the UK-France interconnector on 28th September 2012. The frequency dip recorded by the PAD relay down to 49.72Hz is backed up by the DR frequency measurements from PMUs at the University of Strathclyde, Manchester University and Imperial College London, refer to Figure 10. The small time difference between the PAD relay and PMU records, taking into 1 hour for Summer time saving, is due to fact that the relay clock is not time synchronized so has drifted over time.

7 CONCLUSIONS

The use of an accumulated phase angle drift has been demonstrated in this paper to be an effective means of detecting the loss of grid condition. It was shown to possess good levels of sensitivity at near balance conditions whilst maintaining a high degree of stability under severe fault disturbances. The site trials have indicated a setting of 60° is required to provide stability for large disturbances in the network which is higher than indicated from the RTDS testing. The main impact of a higher PAD setting is that the PAD algorithm will take a little longer to accumulate to the trip threshold when detecting a loss of grid condition, however, a higher setting will help maintain stability for severe power system faults and disturbances. More data will be gathered and analysed from the trials over the next several months to assess the PAD performance and establish the optimal angle setting and algorithm internal parameters. In conclusion, the site trials and RTDS testing indicate that the PAD algorithm is very stable during disturbances resulting from faults and load switching on adjacent circuits but requires a higher setting to ensure stability under major system wide events. Furthermore, an improvement to the existing reference frequency signal estimation can be sought in order to improve the stability, particularly, during system oscillatory events.

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