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IMPACT OF WIND FARMS ON ELECTROMAGNETIC TRANSIENTS IN 132KV NETWORK, WITH PARICULAR REFERENCE TO FAULT DETECTION

Simon LE BLOND
University of Bath – UK
S.P.Le.Blond@bath.ac.uk

Professor Raj AGGARWAL
University of Bath – UK
R.K.Aggarwal@bath.ac.uk

ABSTRACT

Adaptive autoreclosure has been extensively researched as a protection methodology for overhead lines, with well-known advantages over conventional autoreclosure. However, the effect of modern wind farms, specifically power electronics, on existing adaptive autoreclosure methods is unknown. Using the DIgSILENT software, a small part of the UK Generic Distribution System network is constructed as a test system and connected to built-in DFIG and full converter wind farm models. EMT simulations are carried out whilst varying the parameters known to affect single phase-ground fault voltage signatures. The Discrete Wavelet Transform is subsequently applied to these waveforms. Results show that adaptive autoreclosing schemes may need particular attention when designed for DFIG connected lines, although the traditional approach of signal processing and AI is validated since the effect of fault parameters have far more significance than the generating technology concerned.

I - INTRODUCTION

The use of wind generation is increasing globally. In the UK, government targets have set the proportion of renewables in the generation mix at 20% by 2020. Therefore, the impact of wind generation on all aspects of the power systems must be extensively investigated. It is unknown to what extent digital protection algorithms designed for conventional plant, including adaptive autoreclosure, will require modification for wind generation. However, it is well accepted that in future power systems, smart and fast numerical relays will play an important role in preserving security of supply. The need to meet growing demand, coupled with difficulties in building new network, will lead to decreased transient stability margins as operators push more power through the existing infrastructure. Adaptive autoreclosure (AA) is the relay feature whereby the faulted signal is used to diagnose the nature of the fault and designate the most appropriate reclose action. This usually consists of blocking reclosure for permanent faults and reclosing as soon as a transient arcing fault has extinguished. This would be a valuable facility in stressed future scenarios, minimizing transient fault clearance times, optimizing stability and preventing unnecessary shocks to generator shafts. Moreover, systems with larger permeation of wind power must remain connected through grid faults in order to prevent collapse i.e. have ride through capability. An adaptive autoreclose

specially tailored to wind power would help fulfill this criterion by minimizing the number and duration of voltage dips due to reclose operations, and thus ensure smoother transient performance of wind turbines.

II – METHOD

The study was conducted in DIgSILENT's powerfactory. Powerfactory is able to handle electromagnetic transient (EMT) studies and deals with load flow considerations demonstrating the viability of the power system over all timescales. The generating technology was a doubly fed induction generator (DFIG) based wind farm consisting of 9 x 5MW generators, and a 'full converter' (FC) wind farm consisting of 30 x 1.5 MW generators. In all cases, the wind farm was represented by one generator model connected in parallel, using the option in DIgSILENT 'number of parallel machines'. Simulations were compared to a base case of 30 x 1.5MW 'bare' synchronous generators. Since control circuitry governs output of reactive power in the case of the DFIG and FC turbine models, the generation capacities had to be defined in terms of nominal real power rather than apparent power.

i) Test network

The test network, shown in figure 2.1, was a small section of the UK generic distribution system (UKGDS) produced by the BERR funded SEDG centre [1], which is tailored for studies on distributed generation. The particular network used was the EHV2 "Large rural network". This was chosen since bus 7 is a convenient place to connect a hypothetical wind farm. The 13.3km 132kV branch from 106 to 107 represents one of the longest lines in the network representing the farm's likely remote location. Hitherto, adaptive autoreclosure methods have been extensively investigated for EHV transmission lines of 230kV and above. However, wind farms are usually connected at lower voltage levels at either sub transmission or distribution, and thus basing the investigation at 132kV was more appropriate. A load was placed at the receiving end bus. This was to satisfy DIgSIlENT's load flow component and ensure the line was transmitting power during the simulation. The rest of the grid was represented by DIgSILENT's external network component. The short circuit level of the grid infeed was set to a default value of 1000 MVA, approximately twenty times the capacity of the generation at the sending end. The line model was built up using DIgSILENTs 'Type Line' component, taking the values specified by the UKGDS. The line parameters for the

EMT study were calculated by DIgSILENT using a frequency-dependent distributed parameter model. The transformers connecting the generation were built into the DIgSILENT wind farm models, and modelled as ideal transformers, so as not to introduce extra transient behaviour. (This network is shown in figure 2.1).

Figure 2.1: Test network, bus 107 sending end 106 receiving
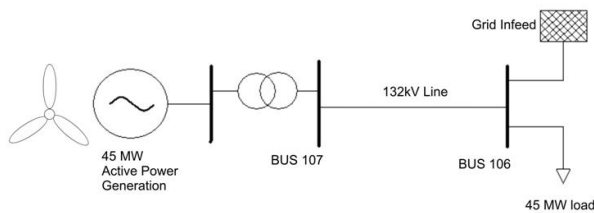
ii) EMT Simulation

Given the information used to determine reclosure would be from the fault itself and the action of the circuit breakers opening, the sequence simulated involved both the fault and subsequent opening of the circuit breaker. The transient simulation was run for one second, the fault inception was at 300ms from time zero and the circuit breakers were set to open at both buses at the nearest current zero after 340ms, with 2 cycles deemed a reasonable response time. The default fault type was a single phase to ground fault. This yields the most information post-circuit breaker by virtue of mutual capacitive and inductive coupling with the healthy phases. The fault path resistance had a default value of 2 Ω, and was simulated by connecting a phase to ground at a "virtual bus" at the middle of the transmission line. The default site of the fault, was at a distance of 6.65km, i.e. at a point equidistant to both ends. The voltage and current waveforms were measured from the sending end bus, where the protection relay would be located. The electromagnetic transient simulation in DIgSILENT was run for 1.1 seconds and at a sampling frequency of 10 kHz. This was a reasonable compromise between speed of simulation and accuracy. The waveforms were subsequently down sampled in Matlab to 1.6 kHz to define appropriate frequency boundaries for the wavelet transform. The resampling process in Matlab for each technology was uniform, so any error introduced by this was systematic.

iii) Discrete wavelet transform

Many adaptive autoreclosing schemes [2] consist of an initial signal processing stage, followed by a pattern selection algorithm. For signal processing, past schemes have utilized either the short time fourier transform or the discrete wavelet transform. The discrete wavelet transform offers the advantage of variable time and frequency resolutions. High frequencies favor time resolution, i.e. high frequency events specifically localized in time but poor frequency resolution. Conversely, low frequency signals

have better frequency than time resolution. This property is useful for non-stationary power system transients that consist of localized high frequency information superimposed on the 50 or 60Hz fundamental power signal. A full explanation of wavelet transforms, and their application in power systems can be found in [3]. For this study the Daubechies DB4 wavelet was used to decompose the original sampling frequency of 1.6kHz to successive details. The frequency bands represented by the details were thus fixed at 800-400Hz, 400-200Hz, and 100-50Hz.

III – RESULTS

Adaptive autoreclose schemes must be robust enough to cope with the wide-ranging fault conditions that may occur on a line, without affecting the diagnosis in terms of phase selection, fault type or transient arcing time. Some of the most important factors that affect the fault signal are: capacity of sending end generation, receiving end short circuit capacity, length of transmission line, fault type, location of fault on line, point of fault inception on wave and fault resistance. For the purposes of this study, a further consideration can be added i.e., the effect of generating technology. [4]

i) Effect of generating technology

In the wavelet transform details, the main feature in all cases is an isolated, high intensity peak across all the frequency boundaries at the fault inception point, and then a smaller but equally ubiquitous spike at the point the circuit breaker opened. This is due to the near vertical wave-fronts on both fault inception and breaker opening, manifesting themselves in the transform as high intensity features at all frequencies. The differences between the FC and conventional technologies are unremarkable, with only minor variations in the frequencies after both events, in the 400-200 and 200-100Hz ranges. See figure 3.1 for conventional case and 3.2 for the FC, and their subsequent wavelet decompositions in figures 3.4 and 3.5. The results show profound differences between the DFIG (figures 3.3 and 3.6) and the other two technologies. With reference to 3.6, there is considerably more noise in the DFIG case over all frequency bands. This is due to the more complex control circuitry featured in the DFIG model, particularly the 'crowbaring' of the rotor current control circuit shortly after the fault inception. In the EMT simulation, the DFIG model automatically implemented this at approximately 0.307s, and removed the impedance at 0.807s. The distortion at the wavepeaks, following the fault inception, but before the A phase breakers open (see figure 3.3) is not present in the other two cases. This is most pronounced at the 200-100Hz and the 100-50Hz intervals, (figure 3.6). Over the healthy phases, the Full Converter model develops unstable oscil1ations 150ms after the fault (figure 3.7), resulting in overvoltages of up to 200% of the base. Comparison against real world data is required to determine whether this is down to

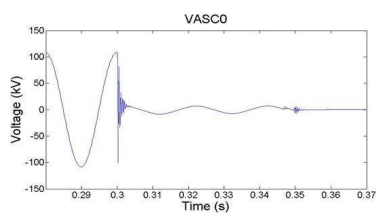numerical instability in the DIgSILENT model or representative of actual behaviour.

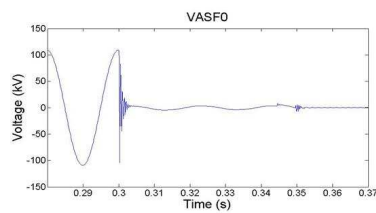Figure 3.1: The conventional default case, faulted phase waveform

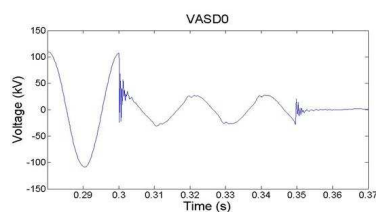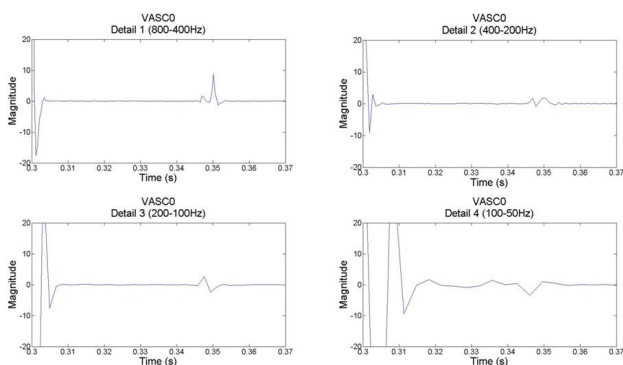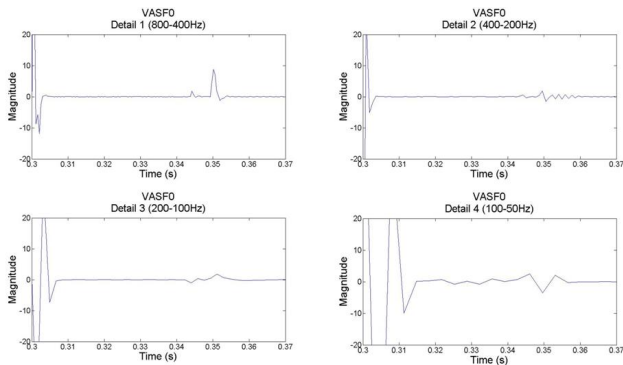Figure 3.2: The full converter default case, faulted phase waveform

Figure 3.3: The DFIG default case, faulted phase waveform

Below, Figure 3.4: The wavelet transform details for the conventional default case, faulted phase waveform

Below, Figure 3.5: The wavelet transform details for the Full Converter default case, faulted phase waveform

Below, Figure 3.6: The wavelet transform details for the DFIG default case, faulted phase waveform
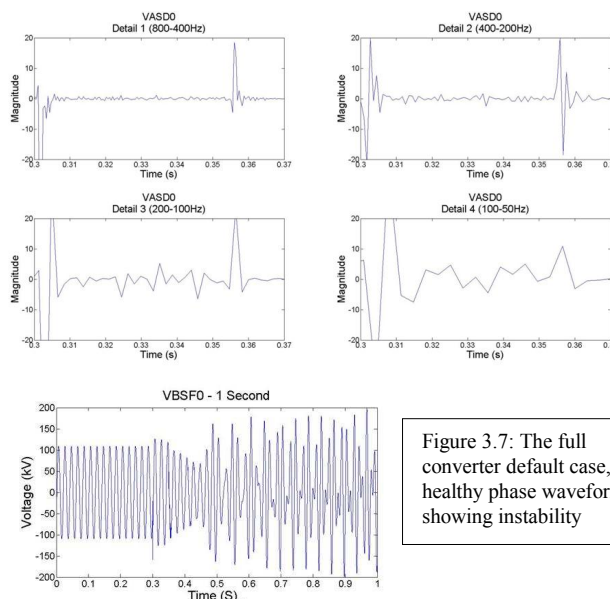

Figure 3.7: The full converter default case, healthy phase waveform showing instability

ii) Sending end capacity

The sending end generation was varied from 150MW to 10.5MW. The Full Converter shows very little variation in the transient signature. This is expected since the Full Converter is fully decoupled from the grid by power electronics and so can maintain current and voltage levels at a wide range of wind speeds and output power. The DFIG simulation fails for capacities higher than 45MW so it is only possible to compare this with 10.5MW. Despite this, the DFIG shows less variance in the fault signatures than the conventional case. This is likely due to the lack of current control circuitry in the conventional generation.

iii) Variance of short circuit capacity

The receiving end short circuit capacity was varied from 35GVA to 100MVA. As would be expected, the main effect across all generating technologies is the level of post fault voltage, which decreases as the local grid becomes weaker. The Full Converter and the conventional technologies demonstrate almost exactly the same behavior across all frequency boundaries. In the DFIG case, the 0.1GVA simulation is not stable. Since this configuration does not represent a valid mode of operation this result can be disregarded. With the strong grid, the features due to breaker opening are approximately ten times higher at the 400-200Hz and 200-100Hz bands in the DFIG case than in the other generator designs.

iv) Length of transmission line and fault location

The line length was varied from 50km to 5km. For all technologies, the transient fault response varies dramatically with the resistance. There are some subtle differences in the frequency bands between different generation types. The overriding trend is much quicker attenuation of high

frequency transients as line length is reduced. This is due to a smaller amount of trapped charge when the phase became isolated by the circuit breakers. This is common to all technologies so the implications for adaptive autoreclosure are minimal.

The location of the fault was varied from 100m from the receiving end to 100m from the sending end. Similarly, the less the amount of line between the measuring bus and fault, the shorter the oscillation time and thus less high frequency transients. There are some minor differences between the technologies, but these are far superseded by the effects of location of the fault. The greatest differences are in the DFIG due to the post-fault noise.

v) Fault type.

The fault type was altered to a three phase to ground, and the response of the circuit breakers adapted for a three phase trip. Although the trends are the same across all three phases, the B and C phases exhibit less intensity since their waveforms are interrupted at a phase shift of either plus or minus 120 degrees from the maxima. The DFIG exhibits very little high frequency information due to the initial fault or the subsequent operation of the circuit breaker compared to the other two technologies.   It would be more useful to compare other more common fault types given this is the rarest type of fault to occur on a transmission line (less than 4%). Unfortunately, DIgSILENT does not allow fault analysis for one section of a distributed parameter line model so this would require alternative simulation software.

vi) Fault inception point on Wave

The timing of the fault was delayed slightly so it occured at half intensity and voltage zero. The effect across all technologies is a decrease in the magnitude of high frequency oscillations due a reduction in the step change. There are very small differences between the technologies apart from the characteristic high frequency noise from the DFIG, which is also observed in the default study.

vii) Fault Resistance

The fault resistance was varied from 0 Ω to 50 Ω. The high frequency features due to both the initial fault and the circuit breaker opening are suppressed more with increasing fault resistance. As can be expected, the post fault voltage level is also greater the higher the fault resistance. These effects are the same across all generating technologies. However, a constant resistance is only valid in the case of a permanent fault. It is well known that transient faults exhibit arcing behaviour, which have a non-linear time-varying resistance. Further studies to show how the electrical arcs interact with wind farms would be beneficial.

IV - CONCLUSIONS

The DFIG showed most variation. This is expected since it is not completely decoupled from the grid, and is therefore more sensitive to grid side transients [5]. In a number of cases, the DFIG simulation was unstable; this is likely to be due to numerical instability caused by the interaction of the complex control loops and the power system. In the DFIG design, the frequency converter must control current in the rotor to maintain synchronism with the grid, but shortly after fault inception the protective crowbar impedance disengages the rotor current control circuitry. The Full converter generally showed very similar variation to the conventional generation. This bodes well for adaptive autoreclosure since this concept is gaining an increasing amount of the market share. However, in many cases the healthy phase became unstable (figure 3.7), putting limitations on the duration of two phase operation on this design, and thus use of single pole circuit breakers. Further work would be beneficial on realistic arc models, and different fault types. Firm conclusions could only be drawn from comparisons with real world data or at least by replicating these results on other software. However, the traditional approach of using wavelet transforms with AI is validated. This is such because only the parameters that showed significant variance with wind generation are those known before the fault (i.e. grid capacity), and these can be accounted for 'pre-fault' in the relay settings. The random unknown parameters determined by fault type (e.g. location-related) had far more influence than the generating technology concerned.

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