Power Swing Protection Relay Realized by a Digital Fault Recorder

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Abstract

Power swings (or power pendelings) are mainly caused by high transmission and triggered by couplings, short circuits, or large power shifts in the grid. Power swings may lead to uncontrolled generation drop-out (machine protection, loss of sychronism) or/and uncontrolled line drop-out (dynamic overload). In addition the power swings may lead to voltage swings or even voltage breakdown. The uncontrolled drop-outs during a power pendeling may have a cascading effect and thereby lead to system-wide faults.

The Norwegian transmission system operator (TSO) Statnett wants to stop power swings before they lead to uncontrolled generation or line drop-outs. This by first detecting a potential harmful power swing, and then control the power swing by reducing power transfer either by introducing a net split or by reducing generation.

The detection algorithm is based on a model of the pendeling, and a sensor algorithm in a Digital Fault Recorder (DFR) estimates the parameters of the pendeling model from an input signal. From the estimated parameters a set of tests are done to decide if the sensor shall trigger.

Statnett has one installation of the DFR serving as power swing relay in service since May 2002, and our second installation is planned spring 2005. The paper describes the swing detection algorithm and summarizes experience gained.

Introduction

In the early 1990's Norway had a surplus of both electrical energy and power, and the transmission grid had good safety margins. Since then the transmission grid has been made more efficient, as there has been no substantial investments in production or grid, and consumption has increased. As 99 percent of the electricity production (~120 TWh/year) in Norway is hydropower, the production will vary with precipitation, but in a normal year Norway is now a net importer of electrical energy. The increased efficiency has led to that the grid safety margins have shriveled, and to compensate for this, system protection schemes have been implemented in the grid.

These system protection schemes are usually implemented in the following manner: An area is connected to the rest of the power system trough a predefined bottleneck. If transfer on the bottleneck exceeds a predefined limit, the power system dispatcher sensitizes the system protection scheme. If the bottleneck is further restricted due to a disturbance (i.e. a set of predefined breaker operations), either production or consumption within the area is automatically tripped by the system protection scheme. The system protection scheme may also introduce a net split.

The drawbacks with the system protection scheme outlined above are:

- The area and bottleneck must be predefined. As both area and bottleneck are dependent on grid configuration, this can be difficult.
- The set of breaker operations that trigger the system protection scheme must be predefined.
- Telecommunication between all the triggering breakers and the triggered system components must be established.
- The distribution of generation within an area will decide if the area is dynamically stable when a disturbance happens. Hence the system protection scheme may be unnecessarily conservative when designing it for the worst case.

- Dynamic stability for a surplus area defined by a bottleneck may be hard to decide, as there exists a plethora of possible disturbances.

Because of the reasons mentioned above, Statnett started in 2000 to investigate the possibility of using a different approach for some of our system protection schemes. The new approach is based on analog measurements on the bottleneck instead of breaker positions. The objective is to detect a power swing on the bottleneck, and when the power swing is potentially harmful the system protection scheme will fire. Therefore was this system protection scheme named Power Swing Relay (PSR).

Statnett decided to use a Ben 5000 Digital Fault Recorder (DFR) as the platform for the PSR. This as:

- The DFR's were already installed in the station with the right inputs for our two test installations.
- The DFR's were equipped with digital output boards, so signaling and integration with the control system was easy.
- The DFR's have proven itself:
    - Reliable with respect to hardware, and with very good self-test systems.
    - Stable with respect to software.
- Very good documentation of system protection scheme response, as the PSR is a part of the DFR.
- The DFR supplier had a good understanding of Statnett's wants and needs.
- Good follow-up of local representative.
- Good in-house knowledge of the DFR.

The detection algorithm for power swings is now a part of the DFR supplier library of DFR sensors (cf. [1]).

Power Swing Detection Algorithm

The power swing detection algorithm is based on a curve-fitting model of a power swing. The model is described by the following parameters (cf. Figure 1):

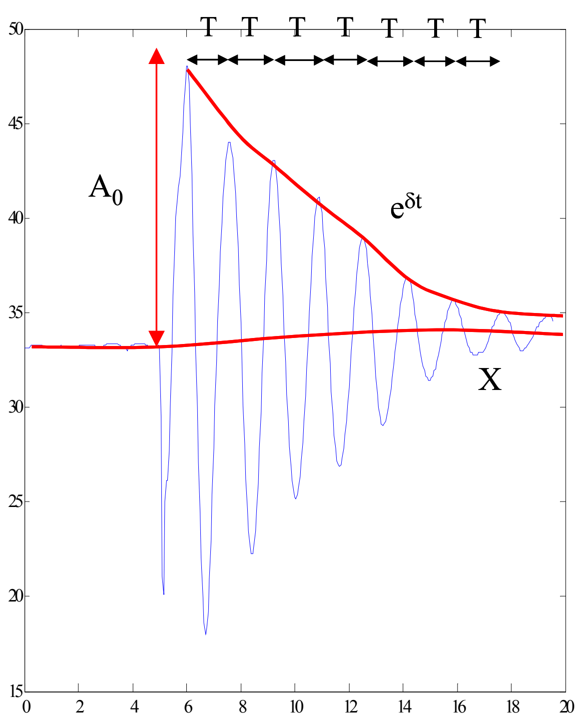

Figure 1 Power swing model

- **Pendeling period (T)**: Time between two maxima.
- **Pendeling damping (δ)**: Time constant of the envelope.
- **Pendeling amplitude (Ao)**: Start value of the amplitude.
- **Mean value (x)**: mean value of the signal.

Based on these parameters the following model of the signal is established for each extrema of the signal:

$$p(t) = x + A_o e^{\delta t} \sin(2\pi t/T)$$

The algorithm implemented in the DFR has three main working modes:

Inactive: The power derivative is monitored until it exceeds a user-defined threshold. This avoids false starting: typical value for the threshold should be 5 times the usual peak-to-peak noise on the power value.

Tracking: This part of the algorithm collects the extrema; ensuring maximum and minimum are interleaved. For an extremum to be retained, it has to be followed by a zone where the signal crosses the mean. For example, an extremum followed by a constant level will not be retained. Practically, the derivative has to be greater than the threshold for two milliseconds. This mechanism ensures that a single spike on the derivative is not interpreted as indicating a change in extremum polarity. Each time a new extremum is retained, a user-defined timer is also started. If the next extremum doesn't occur while the timer is active, the algorithm resets itself completely.

Computing: to extract relevant parameters. Computation is started when three extremas has been obtained, and occurs each time a new extremum is found. In the computing phase new estimates of the model parameters are found for each extremum, an appropriate action is taken according to the estimated values.

The model parameters found during the computing phase are tested against a set of user-defined criteria to decide if the detection algorithm shall fire. The estimated damping (δ) is tested against a user-defined threshold. If the pendeling is well damped (i.e. $\delta < \delta o$) the detection algorithm will not fire. The amplitude (A) of the power swing is also tested, as one only wants detection on "large" power swings. What "large" is, is dependent on the mean value (x). Thus if the ratio between amplitude and mean value is small (typically less than 20%) the detection algorithm will not fire. The proposed solution will not work when the mean value is small, so to avoid spurious triggering in these cases a zero threshold is put on the mean value. The user can also specify a "dead time" (in number of extremas) before the algorithm shall fire. The dead time can be used if the power swing phenomenon exhibits atypical behavior during the first oscillations. Thus to get firing of the power swing detection algorithm three conditions must be met after a dead time: The damping must be "bad", the power swing must be "big", and the mean value of the signal must be greater than the zero threshold. In Figure 2 the behavior of the power swing detection algorithm is shown for three cases.

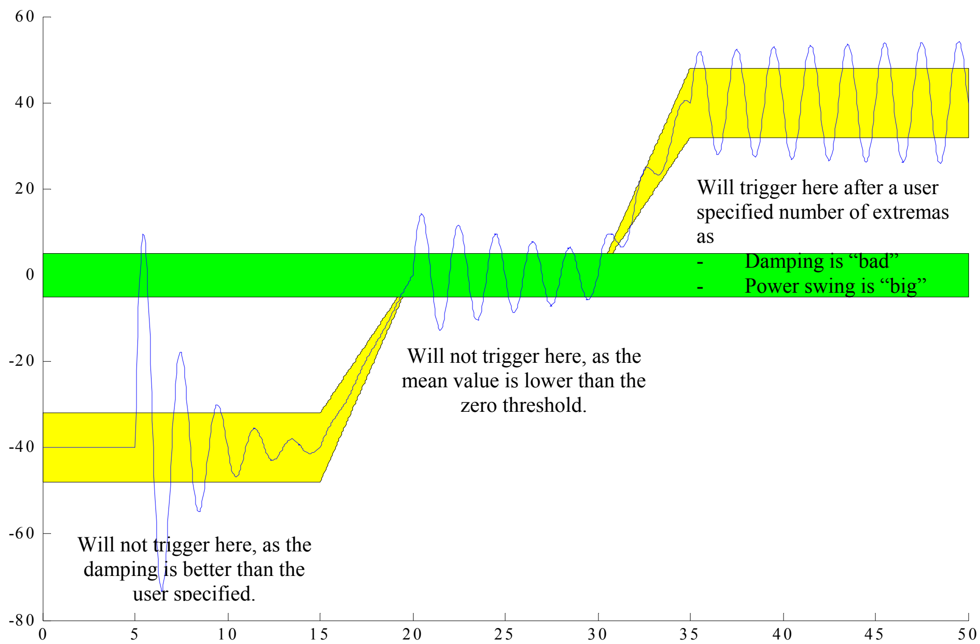

Figure 2 Behavior power swing detection algorithm

Power Swing Relay Planning and Testing

For relay planning purposes a Matlab program was developed, which mimics the behavior of the PSR. A test case is simulated in PSS/E, and the time series for power is fed into the Matlab program. The Matlab program contains the same parameters and algorithm as the PSR. From the given time series the Matlab program extracts the estimates for damping, mean value, amplitude and pendeling period at each extrema.

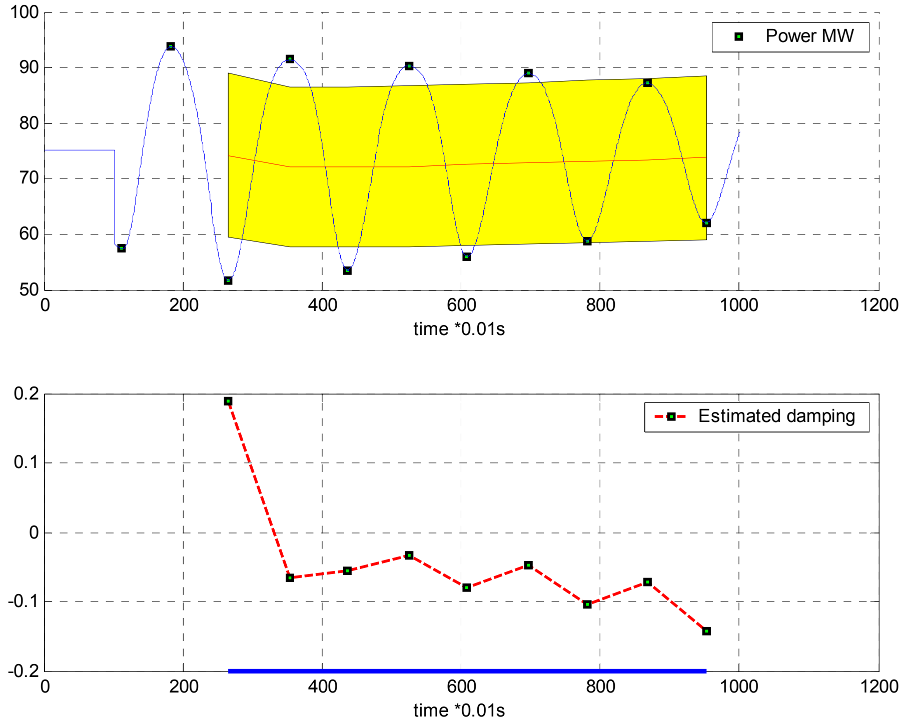

Figure 3 Example Power Swing Relay planning

In Figure 3 is an example of the output of the program shown for a given test signal. The PSR parameters were in this case a threshold on damping of –0.2, and the threshold on the ratio between amplitude and mean value was 20%. From the output of the Matlab program one can see that for these parameter values the estimated damping will be above the threshold. The ratio between mean value and amplitude is above 20% for the eight first extremas, and then goes below. Hence if one wished PSR triggering on this case, the dead time had to be lower than eight extremas.

In the PSR planning phase a collection of test cases are simulated, and simulated PSR response is found from the simulated power time series by the Matlab program. If the simulated PSR response is not acceptable, the PSR parameters are tuned and the test cases are tried again, until the response is satisfactory. The tuned parameters are then implemented in the PSR on-site. To run the test cases on-site, the analog power signal is generated with the use of an analog output card together with a LabView program (cf. [1], [3]). The analog signal is fed into the DFR, and correct PSR response is checked.

Installations

There are two PSR installations scheduled for 2005 in Norway. One is in Fardal on the west coast of Southern Norway. Here the PSR will trip generation within a surplus area via teleprotection when power swings appear on the line out of the area. Power swings may be generated by sudden reduction of consumption (tripping of electrochemical industry) within the area. The objective of this installation is to increase the power transmission limits.

The other installation is in Varangerbotn on the 220 kV line between Norway and Finland in the north. The purpose of this installation is to split the net between Norway and Finland in case of power swings. This to stop Norwegian or Finnish power swing problems from being “exported” on the 220 kV line. The PSR has been installed since 15th of May 2002 for testing in a real installation, but with the net split function inhibited. The Finnish TSO FinGrid and Statnett agreed upon an activation of the net split function in February 2005, and the net split function was turned on.

Experiences

The objective of PSR test installation on the Norwegian-Finnish 220 kV line was to see if the PSR triggered, what it triggered on, and to get some experience with the PSR before commissioning. The PSR was first installed with standard factory parameters. These parameters were:

- A threshold on relative damping (δ) of –0.35.
- A threshold ratio between swing amplitude and mean value of 20%.
- The zero deadband was 10 MW.
- The dead time was 6 extrema.

These parameter settings were installed in the PSR for 18 months. In these 18 months the PSR had 12 triggerings, four on fast auto re-closing, six on short circuits in the grid, one when changing the power flow from 111MW to 15MW and one on a “major fault” in the Nordic grid.

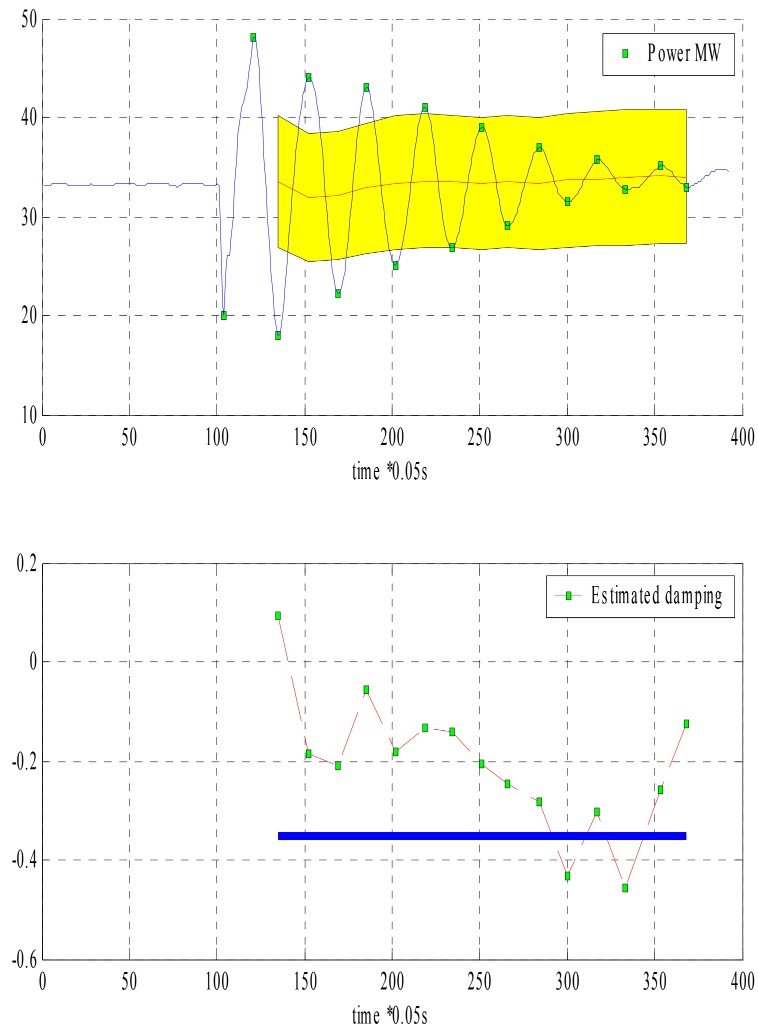

Figure 4 PSR triggering on short circuit

Ten of the triggerings (all on fast auto re-closing, the one when changing power flow, and 5 of the short circuits) were due to that the threshold on the power derivative (i.e. noise insensitivity) were turned to low. The detection algorithm went from inactive to computation mode on noise or on small perturbations. Hence the six extremas of dead time was used before the power swing occurs. The noise sensitivity was retuned and these cases were replayed on the PSR using the relay test method described in the previous section. The problems with noise sensitivity was now gone.   The remaining triggering on a short circuit is shown in Figure 4. To avoid triggering in this case the parameters had to be retuned.

The triggering on a “major” fault was when half of Norway was disconnected form the Nordic grid. This led to power swings (see Figure 5). To avoid triggering in this case the parameters had to be retuned.

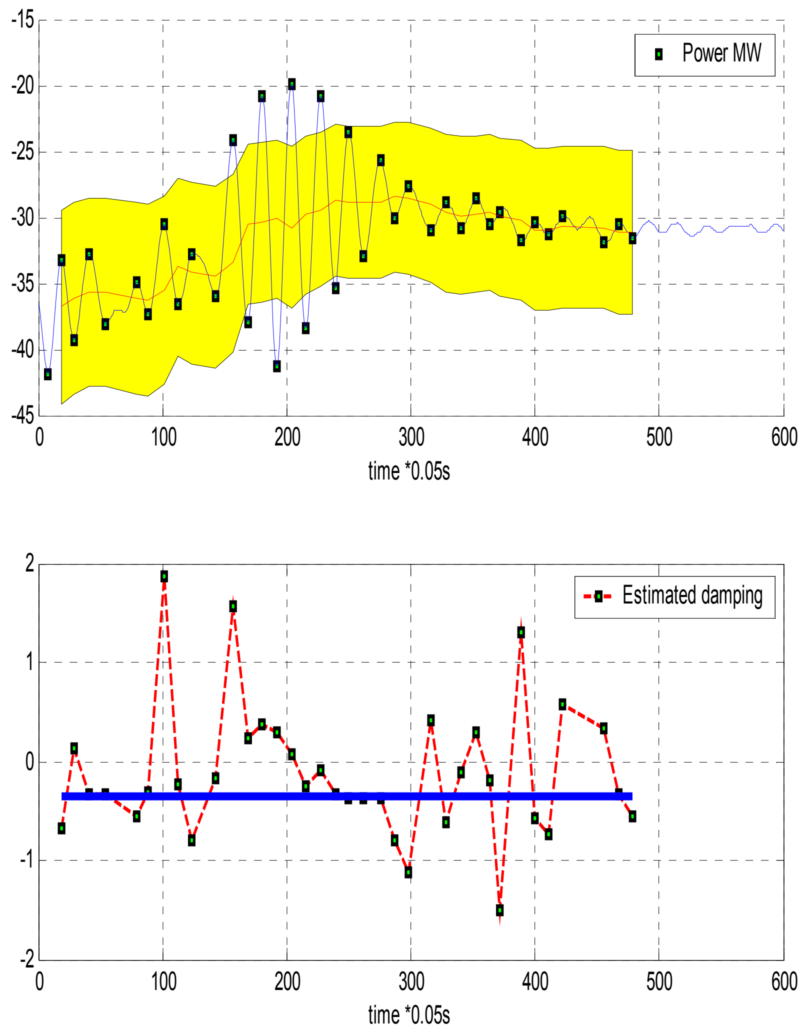

Figure 5 PSR behavior during a "major" Nordic fault

Based on the experience gained in the 18-month test period and the test cases a commissioning of the PSR was carried trough in December 2003. Two instances of the pendeling detection algorithm are now implemented in the PSR. One “start” instance that starts a recording, but does not lead to a net split, and one “2nd zone” instance that leads to a net split. The parameters for the detection algorithms are given in Table 1.

	"start" parameters	"2nd zone" parameters
Damping	-0.3 s^{-1}	-0.2 s^{-1}
Ratio between amplitude and mean value	10 %	20 %
Dead time	6 extrema	10 extrema
Zero dead band	10 MW	10 MW

Table 1 PSR parameter values

There have been no power swings that have lead to triggering of the PSR since the commissioning.

Statnett has proposed higher transmission limits on the 220 kV line, and FinGrid will decide on this in the spring of 2005. In the case that FinGrid accepts higher transmission limits, a "1st zone" detection instance will also be realized. This detection algorithm will operate on 3 extrema dead time, but will only be sensitized when the mean value is over 120 MW. This function will be implemented by a RMS value sensor in combination with the pendeling sensor using the DFR "sensor logic" function (cf. [1] and [4]).

References

[1] Ben 5000 Digital Fault Recorder Reference Manual. RevE January 2002. LEM Elsis, Wavre, Belgium

[2] Lab VIEW User manual. National Instruments, December 2000 Edition.

[3] DAQ 6023E/6024E/6025E User Manual. National Instruments, December 2000 Edition

[4] Ben 5000 Ben 500C Configuration Manual V2.32 99/05/01. LEM Elsis, Wavre, Belgium.

Biography

Jan Åge Walseth was born in 1963 in Alta, Norway. He received the M.Sc. degree in Electrical Engineering in 1988 and the Dr. Ing. degree in Engineering Cybernetics in 1993, both at the Norwegian Institute of Technology. 1993-1995 Walseth worked at Aker Engineering/Oslo developing tools for dynamic modeling. 1995-1997 Walseth worked at Fantoft Prosess/Oslo with design of operator decision support systems/control systems. Since 1997 he has been working at Statnett Regional Operations Northern Norway. His main tasks in his current position are fault analysis, on-site engineering, procurement and commissioning of new control equipment, and control center support.