Operation of a single phase opening/reclosing cycle on an hydroelectric motor-pump : a numerical simulation approach

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Abstract

A single phase arcing fault to ground appearing on an extra high voltage (EHV) line can be eliminated by an opening / reclosing cycle of the distance protections enclosing the fault. This operation could cause the synchronous machines of the power plant, supplied by this line, to lose synchronism. In this paper, a numerical simulation of several cases of single phase cycles on a large hydroelectric motor was carried out, thereby determining the main parameters influencing the success of this sequence from the viewpoint of the motor dynamic stability .

1- Introduction :

When a single phase arcing short circuit to ground appears on a plant-station line, the nearest distance protection can start for a single phase opening / reclosing cycle in order to isolate the fault and to guarantee a maximum service continuity [1] .
Such a process involves the fact that we know the dynamic behaviour of the motor which may lose synchronism during the transient operational conditions. A practical case of a single phase cycle on a large hydroelectric motor-pump is studied, and it will be proved that the motor's initial field excitation, the performance of its voltage regulator and the short circuit impedance of the power system are the essential factors for monitoring the machine stability. The transient stability limit defined as the critical reclosing time is then found for several cases of initial machine conditions and different power system reactances.

2- System description :

The system configuration shown in fig 1 represents a case of a large salient pole synchronous motor connected trough a grounded transformer to a given system bus. To take into account the variation of the supplied power system including the contribution of other synchronous machines on the power system, the equivalent short circuit reactance is modelled by a reactance xcc ranging from xcc = 0.01pu to xcc = 0.09 pu .

The EHV line connecting the transformer to the system is of 200 km long. This line is equipped by two distance protections Px1 and Px2 acting in 100 ms and in 120 ms corresponding to a fault seen on a first and a second stage [2]

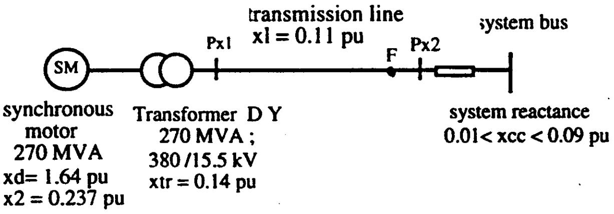
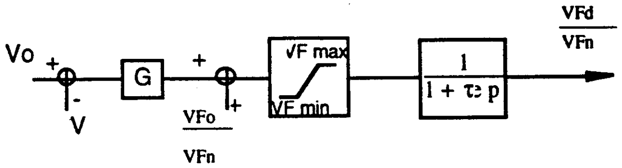


Fig 1 : The system studied

The parameters of the synchronous motor are given in the appendix, and its rated characteristics are used to define the per unit system. During the steady state operation, the motor's field excitation is monitored by the amount of delivered or absorbed reactive power. For this case, the maximum reactive power that the motor could absorb is Q = -130 MVAR.

The study is carried out by an electromagnetic transient simulator [3] .The synchronous motor equipped with an automatic voltage regulator is modelled using Park's formulation [4]. The automatic voltage regulator is simulated from the following block diagram (fig 2):



where

p : Laplace operator
G : regulator gain
τe : excitation time constant
VFd : excitation voltage
VFn : rated excitation voltage
VFo : initial excitation voltage
V : stator voltage
Vo : reference voltage

Fig 2 : Automatic voltage regulator

The motor-pump mechanical system is represented by one mass of inertia constant of 4 s and simulated using the differential equation of the motion . Mechanical damping can be neglected. The mechanical input torque is considered as constant during the transient operation, which is a good approximation of a practical system because of the short duration of the considered transients .

3- Analysis of simulation results :

Assuming that at $t = 0$ a single arcing fault to ground on phase a occurs at point F of the transmission line (see fig 1), the following sequence will be performed :

- $t = 100$ ms, first stage single phase opening of Px2 : motor is supplied by two phases and the fault is still seen by the motor .
- $t = 120$ ms, single phase opening of Px1 : The fault is isolated : purely a two-phase motor operation .
- $t = 1600$ ms : simultaneous reclosing of Px1 and Px2, after extinction of the arcing fault .

To point out the influence of the initial steady state of the motor (Po,Qo), its voltage regulator gain and short circuit reactance of the power system, the four following cases are considered :

case 1 : Initially the motor is operating, in steady state, with rated output torque and is supplying reactive power to the system (synchronous compensator motor) : Po = 240 MW, Qo = + 100 MVAR, $\cos(\phi) = 0.91$ (leading) xcc = 0.01 pu, G = 10 and $\tau e = 0.03$ s (static excitation system) .
Curves of the electromagnetic torque Ce, the rotor angle δ and the slip g in Fig 3 show that the motor does not lose synchronism during the two-phase operation . After reclosing, the arcing fault is already extinguished then damped oscillations of the motor variables would subsist about three or four seconds until the motor will reestablish again its initial steady state operation.

case 2 : Initially the motor operates with rated output torque and absorbs reactive power from the system :
Po = 240 MW, Qo = -100 MVAR $\cos(\phi) = 0.91$ (lagging), xcc = 0.01 pu, G = 10 and $\tau e = 0.03$ s .
Obtained results of Ce, δ , g are represented in fig 4 and show that the motor lose synchronism during the open phase operation about t = 650 ms and does not recover after reclosing .

case 3 : Initially the motor operates all the same as for case 1 but with a higher power system reactance xcc equal to 0.09 pu.
The simulation results show that the motor lose synchronism in this case around 600 ms as for case 2 .

case 4 Initially the motor operates identically as for case 2 but with a voltage regulator gain G = 15 : it is shown that the motor do not lose synchronism in this case contrary to case 2 .

These results illustrate that single phase cycle operation on a salient pole synchronous motor can be performed successfully, depending on its initial field excitation, its equivalent impedance with the system and the performance of its automatic voltage regulator.

4- Critical reclosing time :

Reclosing of the opened phase is operated at tc =1600 ms for all the previous cases followed, to leave enough time for the arc to go out [5]. However this value of the

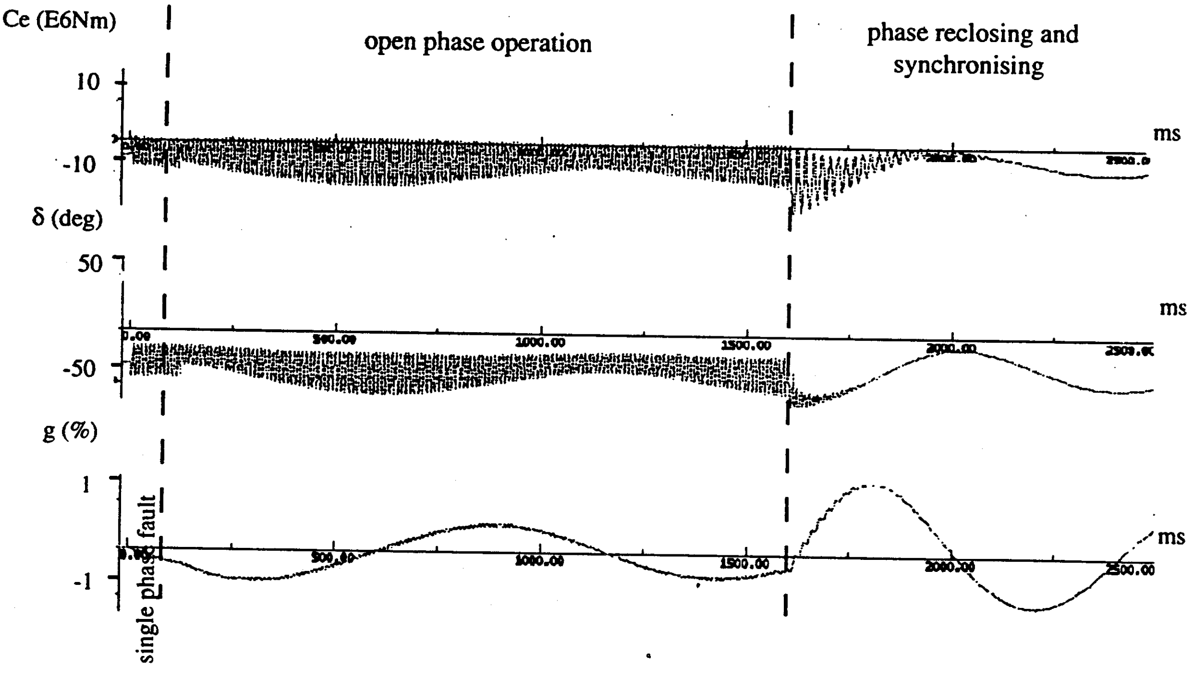


Fig3 : successful single phase cycle

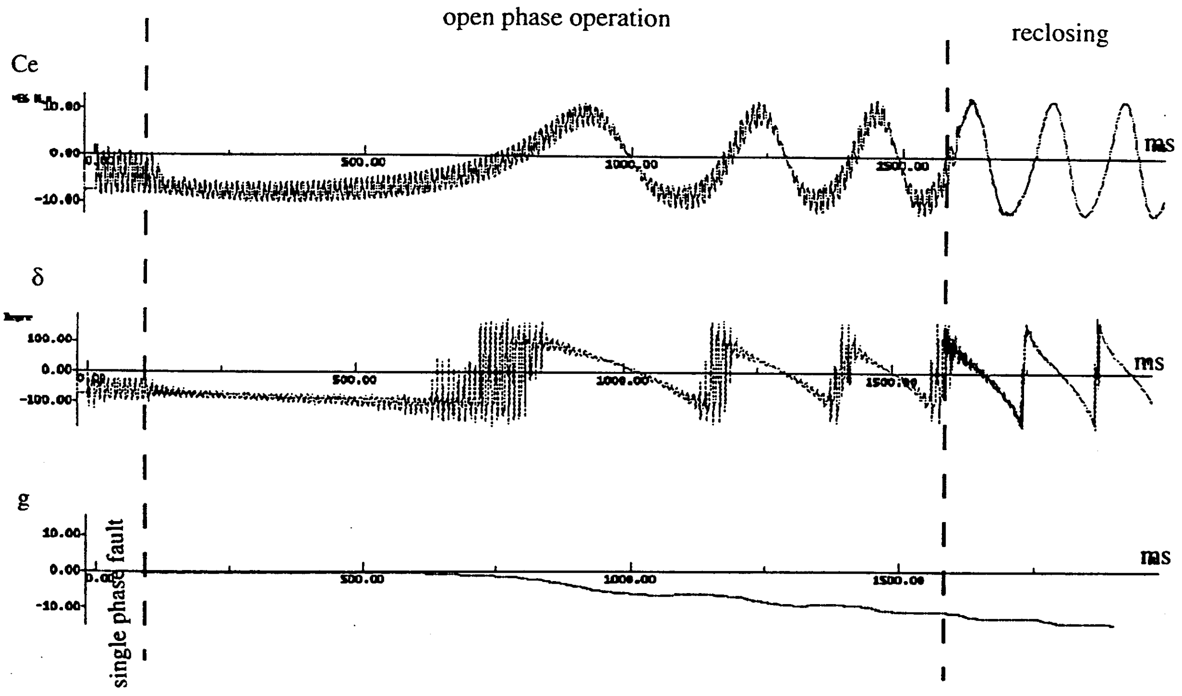


Fig4 : loss of synchronism during a single phase cycle

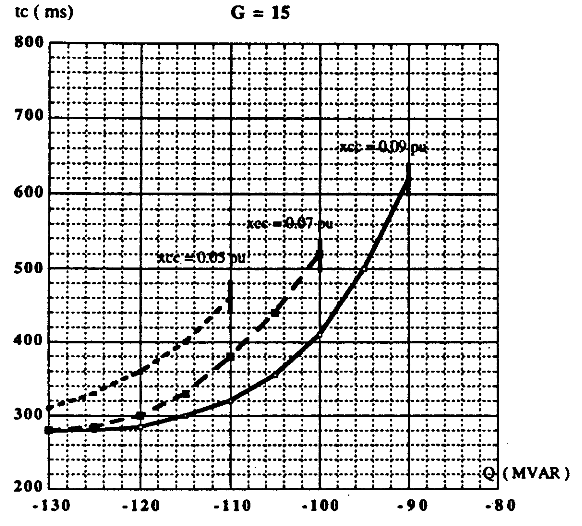


Fig 5 : Critical reclosing time versus reactive power for different given values of xcc

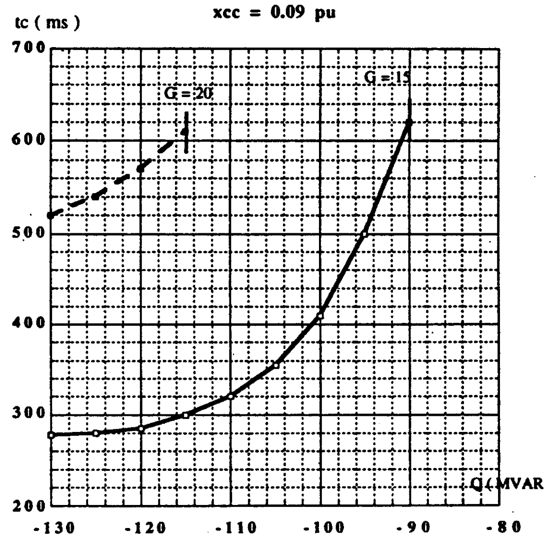


Fig 6 : Critical reclosing time versus reactive power for different 'values of the regulator gain G

reclosing time seems to be much big for cases 2 and 3 where the motor lose synchronism at 650 and 600 ms, respectively. A critical reclosing time will be defined then for the unstable cases as the least time necessary to reclose the open phase and the motor just remains in synchronism : a slight increase of the open phase period would cause the machine to slip poles and to lose synchronism .

To get more details about the influence of the different parameters on the synchronous motor stability under a single phase cycle, the evolution of the critical reclosing time will be found as a function of the motor delivered reactive power and this is for different cases of the system reactance and the voltage regulator gain .

Figure 5 shows plots of the critical reclosing time versus initial reactive power delivered by the motor with a given voltage regulator gain G =15 and different system reactances (xcc = 0.05 pu, xcc = 0.07 pu, xcc = 0.09 pu). Figure 6 shows plots of the critical reclosing time versus initial reactive power absorbed by the motor with a given system reactance xcc = 0.09 pu and different voltage regulator gains (G = 15 and G = 25).

For each case, there exists a limit of the absorbed reactive power Qlim above which the motor is always stable under the single phase cycle independently of the reclosing time. This limit is represented by a solid line in figures 5 and 6. It is evident from these figures that the limit of the motor absorbed reactive power, Qlim, above which the single phase cycle is successful independently of the reclosing time, increase with decreasing values of xcc and with increasing values of the regulator gain : the most constraining case consists of an operating with power system reactance xcc = 0.09 pu and an initial steady state motor working with a maximum reactive power absorption (Qo = -130 MVAR). This case become stable if the voltage regulator has a gain of G = 3 0, that is to say for this considered power system, if the motor is equipped by an automatic voltage regulator of a gain $G \geq 30$ and a time constant $\tau e = 0.03$ s (static excitation system), a single phase switching sequence can be performed successfully to eliminate an arcing line-to-ground fault on the EHV line, whatever are the reclosing time and the initial steady state motor operation .

5- Conclusion :

A computer aided study of an opening / reclosing operation cycle on an hydroelectric motor-pump group after a single phase fault has been carried out. It has been shown that loss of stability depends essentially on the initial balanced steady state operation of the machine, its voltage regulator performance and the equivalent power system short circuit impedance. For several cases, the limit of the absorbed reactive power, Qlim, above which the motor is always stable under the single phase cycle was found. Otherwise, reclosing beyond the critical reclosing time would cause the motor to slip poles and to lose synchronism. Further analytical approach to study the influence of the previous parameters on the critical reclosing time will be carried out to confirm these numerical simulations. These results will also be validated by test on a large hydroelectric motor . This approach must be extended to study problems of electromechanical stress during reclosing and physical phenomena of the arcing fault extinction.

6- References :

[1] KIMBARK A.W " Supression of Ground-Fault Arcs on Single-Pole-Swiched EHV Lines by Shunt Reactors " IEEE Trans. Power Apparatus and System, vol. 83, pp 285-290, March 1964.

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[4] ADKINS. B and HARLEY. R.G " the general theory of alternating currrent machines " Chapman and Hall Ltd 1975

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Appendix : synchronous machine parameters

The per unit parameters are on 270 MVA / 15.5 kV base

Rating (MVA)		270
Line to line voltage (kV)		15.5
Power factor		0.91
Pole number		20
Speed (rpm)		300
Reactances (pu)		
synchronous direct reactance	xd	1.61
transient direct reactance	x'd	0.37
subtransient direct reactance	x"d	0.4
quadrature reactance	xq	0.96
subtransient quadrature reactance	x"q	0.29
inverse reactance	x2	0.36
leakage reactance	xs	0.14
stator resistance (pu)		0.005
time constants (s)		
T'do		0.09
T'qo		0.14
Tdo		6.58
Ta		0.63