Conversion of PSSE data file to ATP format for a study of voltage sags in an aluminum factory

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Abstract-- **An aluminum factory has experienced several load shedding as result of faults in 500 kV overhead lines of the electric grid, external to the plant.**

The load shedding from two of the four potlines of aluminum production, are consequence of the actuation of the protection system against voltages sags installed on the thyristors rectifiers, which under certain conditions considered dangerous, causes the trip of the rectifiers to avoid possible damage to the thyristors due to commutation failure, shedding in this way 360 MW of the total load of the aluminum factory.

In order to assess the sensitivity of the protection system to voltage sags caused by faults in the external network, a comprehensive study of the system was performed through digital simulations of failures in several overhead lines, considering different types of faults, locations, scenarios, etc.

The parameters and topology of the network are available in detail in the PSS/E program power flow files, but since it is necessary to determine the waveform of the voltage at the plant bus bars, the studies must be performed with a program able to calculate electromagnetic transients such as the ATP. A program was developed to make the conversion of the PSS/E power flow data to ATP format.

This paper presents a description of the program, together with the results and conclusions of the study.

***Keywords*: ATP, EMTP, Voltage Sags, Thyristor Rectifiers.**

I. INTRODUCTION

An aluminum factory has experienced several load shedding as a result of faults in 500 kV overhead lines of the external electric grid of the plant.

Two of the four potlines of aluminum production (180 MW each), are with thyristor rectifiers, and have a protection system against voltages sags, called 'Low Synchronism Voltage Protection' ('LowSync'). Under certain conditions considered dangerous, the protection disconnects the rectifiers to avoid possible damage to the thyristors due to commutation failure, shedding in this way 360 MW of the total load of the plant.

It has been verified in real operation that the protection has tripped the rectifiers with, for example, an asymmetric fault of a 500 kV overhead line, at a distance greater than 350 km from the aluminum factory.

In order to assess the sensitivity of protection 'LowSync' to voltage sags caused by faults in the external network, a comprehensive study of the system through digital simulations of faults in several overhead lines has been performed.

The study considereddifferent types of faults, locations of the faults in the line, scenarios, etc.

The parameters and topology of the Argentinean electric power grid is available in PSS/E power flow files, but since it is necessary to determine the waveform of the voltage at the plant bus bars, the studies must be performed with a program able to calculate electromagnetic transients such as the ATP [1].

Furthermore, the study involves the simulation of many cases that take into consideration single and two-phase faults, with and without ground contact, on several lines in various scenarios of high and low demand, and with different locations of the fault in the line.

Given the large number of cases to be simulated, and in order to construct scenarios with the PSS/E program and then reuse this data with the ATP, an IPLAN program [2] was developed to generate the data files in the required format by the ATP, by converting the PSS/E load flow files.

In this way it was possible to build and run a total of 284 cases with the ATP program, considering one-phase and two-phase faults with and without ground contact in 12 transmission lines (11 of them are 500 kV and one 330 kV), and other bus bars of the grid, using 12 different scenarios.

II. SYSTEM DESCRIPTION

Fig. 1 shows a representative diagram of the connection of the aluminum plant with the network.

The aluminum factory has four potlines with a total load of 720 MW. Two of the potlines rectifiers were recently changed to thyristor technology, while the remaining two still use diode technology.

The plant is supplied by a hydro power plant (4 x 118 MW) interconnected with the aluminum factory through two 330 kV lines. The plant also has an internal generation of approximately 730 MW.

Since 2006 the plant is also interconnected to the main Argentinean transmission system (SADI) thought a 500 kV radial power line of approximately 354 km long.

The replacement of the rectifiers to thyristor technology

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added a voltage sag sensitivity problem to the equipment, and the interconnection with the SADI increased exposure to the faults in the network, which are the main cause of the voltage sags.

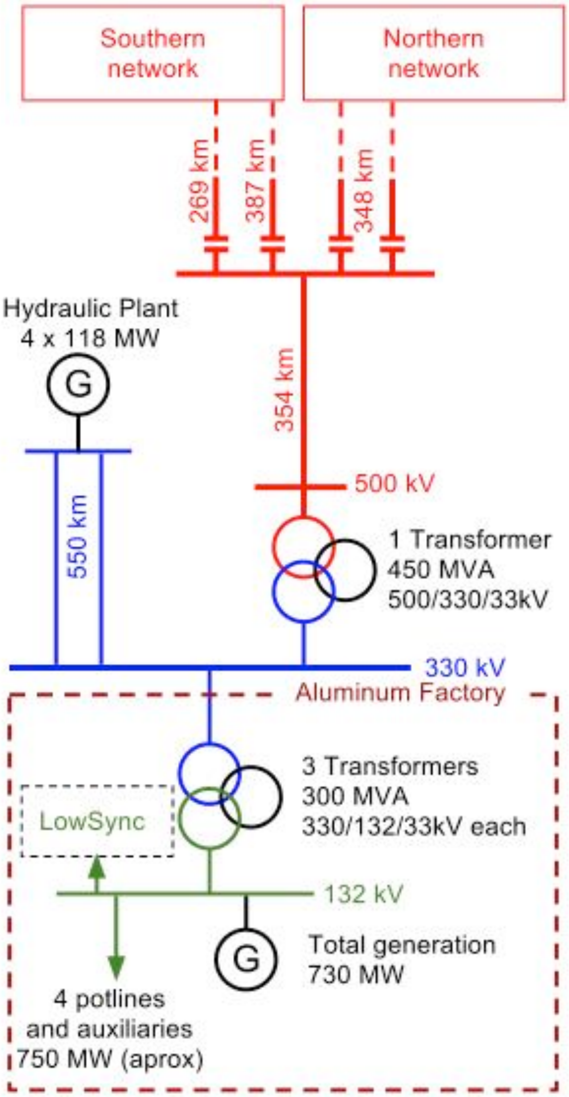

Fig. 1 Representative diagram of the aluminum factory network.

A. Load shedding incidents due Low Synchronism Voltage Protection

The Low Synchronism Voltage Protection (in short, 'LowSync') is installed at the 132 kV bus bars of the plant, at the high voltage side of the rectifier transformers, and on both potlines with thyristor-based rectifiers.

This protection calculates the envelop of $V_{max}(t)$, which is equal to the maximum value of the instantaneous absolute values of network phase-to-phase voltages.

In the case of a moderate voltage network perturbation , due to, for example, a short circuit on a line far away from the plant, the protection acts instantaneously changing the rectified angle from 17 to a value of 40 degrees. The potline continues working but in 'degraded mode', with a decrease of the potline current during a maximum time of 1 s. The protection assumes this situation if the envelope falls below the level of 0.75 p.u.

However, if the envelope continues to decline and falls bellow the level of 0.6 p.u. for at least 2 milliseconds, the protection assumes a large perturbation in the voltage network, and to avoid a possible commutation failure, the firing is stopped (and consequently the current). The HV breaker of rectified transformers is then tripped. This is the worst case scenario, only expected for faults near the plant. However, in the operation of the system it was verified to occur for faults located far away of the plant.

Fig. 2 shows the registered waveforms of the input signals to the LowSync, for one of the real cases when two potlines (360 MW in total) was tripped due to the action of the LowSync protection. It was a two-phase fault in a 500 kV line, located at approximately 360 km away from the plant. This kind of behavior is certainly not expected in a case like this.

The part a) of the figure is the phase-to-ground voltage measured by the LowSync protection on the 132 kV bus bars. Part b) and c) are obtained processing this voltages with Matlab. Part c) is the envelope of Vmax(t), the input of the LowSync protection.

Part d) corresponds to the currents on the rectifier transformers, measured at secondary of current transformers (CT).

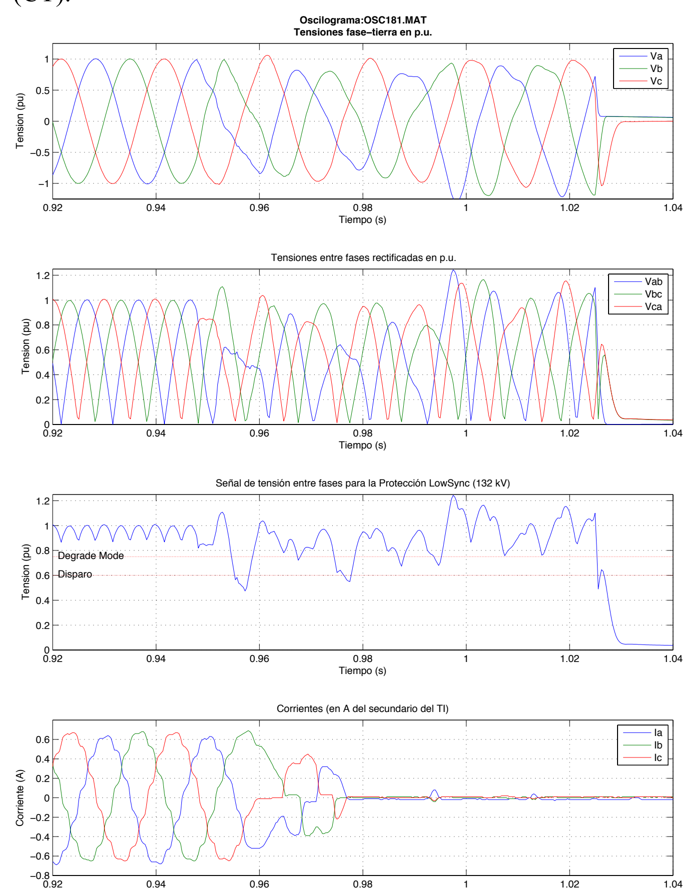

Fig. 2 Processing with Matlab of a fault register; a) phase-to-earth voltages, b) Vmax(t)=phase-to-phase absolute voltages, c) envelope of b), d) Current on rectifiers measurement current transformers.

It is evident that no high frequencies are involved in the phenomenon, and that the voltage sag that produces the protection trip occurs immediately after the two-phase fault.

III. Preliminary analysis

A preliminary analysis of the transients was done in order to determine the requirements of the network model: what needs to be modeled and what does not?

Judging by the observation of the logs, it can be deduced that is not necessary to consider the variation of the parameters with the frequency, neither the generator control systems.

However, to determine the influence of other elements and parameters, some simulations with the ATP were performed with a simplified model of the network.

To begin with, this model allowed to determine that the actuation of the surge arrester protection of series capacitors in the line in fault has an important influence in the voltage waveform and therefore in the shape of the envelope of Vmax(t). Because the surge arresters data are not included in the PSS/E power flow files, the models must be added to the ATP file for the IPLAN program by other way.

Secondly, it is important the instant when the fault occurs with respect to the waveform of the voltage. It was also found that this instant is more or less important depending on location on the line where the fault was applied.

For example, Fig. 3 shows the envelope waveform for different instants of the fault with respect to the voltage waveform, if the fault is applied at a distance of 10% of the line length.

Fig. 4 shows the same but for a fault located at 50% of the same line. Both figures show that the worst situation is when the time of the fault is at a maximum value of the envelope. This is assumed for all simulations.

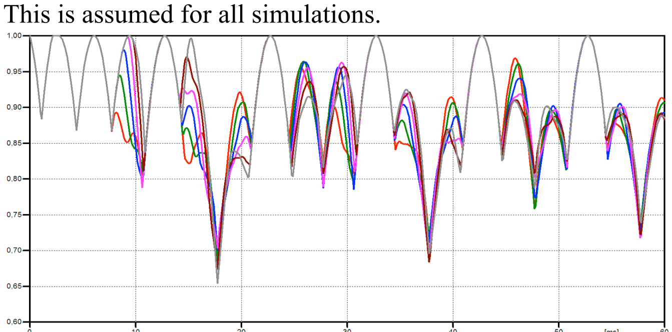

Fig. 3 Input signal to LowSync protection for a simulated fault at 10% of length of the line for different instant with respect to the voltage wave.

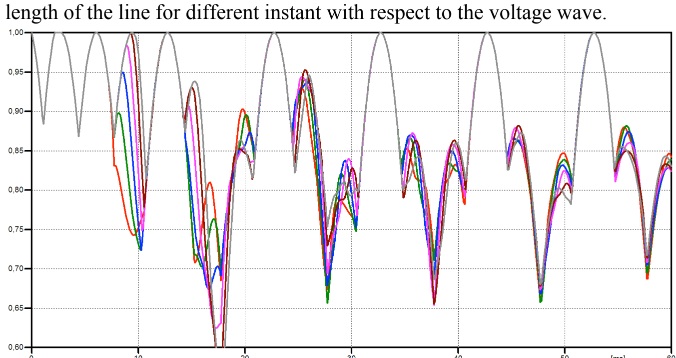

Fig. 4 Input signal to LowSync protection for a simulated fault at 50% of length of the line for different instant with respect to the voltage wave.

Third, the group connection and phase shift of the transformers also have influence on the resulting envelop of Vmax(t). The problem is, these data are generally not included in the PSS/E power flow data case. The solution adopted in this case was to represent in detail the transformers that interconnect the 132 kV bus bars of rectifier transformers, with the 500 and 330 kV voltages levels.

IV. Data conversion from PSS/E to ATP

The main work was the data conversion of the PSS/E files to ATP format.

Because there are many cases to analyze, it is necessary to build the ATP data cases with an automatic processing of the power flow files.

This has been done with an IPLAN program, that makes the ATP data cases with all the necessary elements to run the simulation with batch processing in the MS-DOS environment, without using the ATPdraw program.

The completed sequence use for this automatic processing is:

1. Build all the necessary power flow scenarios with the PSS/E
2. Write and use an IPLAN program to convert the power flow data on each scenario to ATP format.
3. Run all the cases with the ATP, at MS-DOS command prompt with batch files.
4. Convert the ATP plot output files from PL4 format to Matlab.

The main problem is that the numbers of elements in the network exceeds the dimension of the ATP, so it is necessary to do some network equivalents. This should be automatically done by the IPLAN program.

Also, because it is not possible (nor necessary) to represent the generators with the synchronous machine model, they were simulated with the ideal source model and the sub synchronous reactance of the generator. The amplitude and angle of the voltage source was read from the power flow files by the IPLAN program.

However, in this way it cannot be taken into consideration the negative sequence reactance of the generators, but, since the faults are applied away from the generators, this is considered as a second order error.

After converting the power flow data, the IPLAN program has to add the series capacitor surge arresters and the LowSync protection models .

For the location of the fault in the line, it is used the SPLIT activity of the PSS/E to add a dummy bus bar at the desired location.

For each scenario, line in fault, location of the fault and kind of fault, the IPLAN program generates one ATP data case.

For example, for a two-phase fault without ground contact (2F), located at 50% of the line between buses 2000 and 2012 of the PSS/E power flow, and in the scenario named ‘PV12_BASE’, the name of the file generated for the IPLAN program is:

```
PV12_BASE_50PCT_2000-2011-2_2F.atp
```

A. *Modeling of the protection system 'LowSync'*

The 'LowSync' protection is simulated with MODELS language (see Appendix I).

The model calculates the envelope of Vmax(t).This is an output of the model, but it does not trip the potlines in the ATP network model. The results of the run are written in the models.1 file on disk, indicating if the LowSync protection sends the signal to trips the potline, change his operation to 'degrade mode' or do nothing.

The code is saved as a library in the disk (it is the same code for all cases), and the IPLAN program adds it into the ATP file with a $INCLUDE sentence.

A batch file used to run the simulations changes the name of the file from models.1 to the name of the run case.

B. *Including Surge arresters of series capacitors*

For the models of the surge arresters, a similar approach was taken to the one that has been used for the LowSync protection. In other words, a LIB file was created for all surge arresters models, and include for the IPLAN program into the ATP file with a $INCLUDE sentence.

V. Running the ATP cases

All the cases are executed through batch's command files in the MS-DOS environment.

First, a batch file is used to execute a single ATP file. The name of the file to run is indicated as a parameter of the batch file (the %1).

Batch file to run one case:

```
REM file run_1case.bat
DEL models.1
tpbig %1.atp
COPY models.1 %1.res
```

More batch's files are used to run a group of cases, for example the following batch file runs four cases, for a specific location of the fault, indicated in percent has parameter (%1):

```
REM
REM B.BLANCA - OLAVARRIA
CALL run_1case PV12_BASE_%1PCT_2000-2011-2_2F
CALL run_1case PV12_II_%1PCT_2000-2011-2_2F
CALL run_1case VV12_VI_%1PCT_2000-2011-2_2F
CALL run_1case VV12_VIII_%1PCT_2000-2011-2_2F
REM
del *.dbg
```

A. *Collecting results*

The results are collected in two ways:

a) Through the models.1 files of LowSync MODELS. This file contains the minimum value of the envelope of Vmax(t), and the time when the LowSync protection send the signal to trip or change to 'Degrade Mode'
b) Graphically, with PL4 output of ATP.

It is impossible to see and analysis all the PL4 outputs with the PlotXY, so these files were converted to Matlab with the 'convert.exe' program that comes along with the PlotXY files.

Fig. 5. shows an example of the PL4 output processed with Matlab, for a fault similar to that shown in Fig. 2.

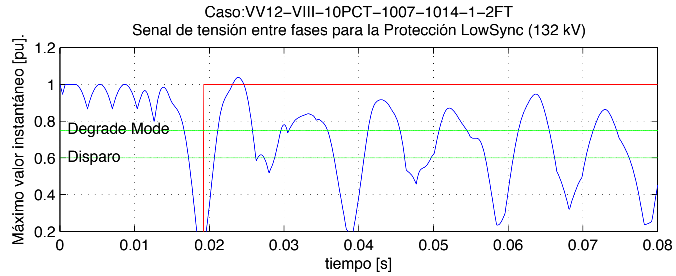

Fig. 5. Envelope of Vmax(t) at 132 kV bus bars for a fault at more than 350 km from aluminum factory. Red line indicates that LowSync send the trip signal, and the time when this occur.

VI. Results Summary & Analysis

Due to the extension of the study results, they are summarized in Table I for faults in 500 kV lines, and Table II for the 330 kV double-circuit line. The tables show the number of analyzed cases, and the percentage that causes the trip of the potlines or the change to 'Degrade Mode', for actuation of the LowSync protection, or if the fault doesn't have any consequences at all (column 'ok').

One of the observations from the results was that the consequences of two-phase fault are similar whether there is contact with the ground or not, so they were placed together in the tables.

The faults in the only 500 kV line that interconnects the plant with the EHV transmission system was analyzed in detail simulating the three kind of faults, at 10%, 50% and 90% of the line length, and in all scenarios.

It was observed that 19.4% of one-phase fault cases, and 90.3% of two-phase faults will produce the shedding of the two potlines, while the rest will change their operation to 'Degrade Mode', so, in case a fault appears in the line, there will be some consequences in the operation of the potline, no matter where they occur.

TABLE I
Summary of results for all the cases analysed in 500 kV lines

Distance to the fault & kind of fault	#Cases	Trip	DM	Ok
Less than 350 km				
1 phase	36	19.4%	80.6%	0%
2 phases	72	90.3%	9.7%	0%
350 to 700 km				
1 phase	30	0%	70%	30%
2 phases	60	45%	55%	0%
More than 700 km Only 2ph fault, at 50% of line length	44	20. 5%	63.6%	15.9%

For faults in other 500 kV lines, located at a distance from

350 to 700 km of the plant, none of the one-phase fault will produce the trip of the potlines. For 70% of these a change to 'Degraded Mode' operation will occur. For two-phase faults, 45% of them still produce the trip of the potlines, most of them for minimum demand scenario, and fault located in the end closest to the plant.

For faults on power lines located at more than 700 km, only two-phase faults without ground contact were simulated and only at 50% of the line length. Even at this great distance from the plant, in 20.5% of the cases a disconnection of the potlines will occur, all of them with minimum demand scenarios.

Table II shows the summary for faults in one of the two circuits between the aliminum plant and a Hydraulic plant situated 550 km away.

Faults in this lines will have less consequences than the ones for the 500 kV line connected to the aluminum factory, but it is still posible that they tripout of the potlines for one-phase faults. Most of the tripouts occur for faults that are close to the aluminum plan, and minimum demand scenarios.

TABLE II

SUMMARY OF RESULTS FOR ALL THE CASES ANALYSED IN THE 330 KV LINE

Kind of fault	#Cases	Trip	DM	ok
1 Phase	12	16.7%	66.7%	16.6%
2 phase	24	33.3%	50.0%	16.7%

VII. CONCLUSIONS

A program to convert PSS/E power flow data to ATP format was developed, as part of a methodology for evaluating the performance of the LowSync protection against a wide variety of electrical network failures.

The main conclusions of the study are: the continuity of the operation of the two potlines with thyristors rectifiers is highly exposed to two-phase faults (with or without ground contact) within a wide area.

The load shedding probability decreases with increasing distance to the fault, but it is quite high even for remote faults.

The scenarios with minimum demand are the most critical, as there is less in-service generating units that contribute to the support of voltage.

Because it was necessary to make some networks equivalents due ATP limits, and the problems to considerate parameters like transformers phase-shift and negative sequence of synchronous machines, the numerical results must be considered approximated, but still a good global evaluation of the performance of the LowSync protection behavior.

VIII. REFERENCES

[1] Alternative Transient Program (ATP) RuleBook, Leuven, Belgium. Leuven EMTP Center, 1987.

[2] PSS/E 30.2 IPLAN Program Manual, Release 17. Power Technologies International (PTI), SIEMENS Power Transmission & Distribution, Inc.

IX. APPENDIX I

Bellow this text there is the code of the 'LowSync' in MODELS language.

```
/MODELS
MODELS
INPUT
M0002A {v(INA)}
M0003B {v(INB)}
M0004C {v(INC)}
OUTPUT
  OUT
  DISP
-- MODEL LOWSYNC ------------------------------
MODEL LowSync
INPUT  va,vb,vc
OUTPUT signal, trigger
VAR
 vab,vbc,vca,aux,maxi,signal,ta, trigger
 prt, tdisp, minv, DMreset, DMcount
INIT
 signal:=0, ta:=0., trigger:=0, maxi:=0
 prt:=1, tdisp:=0., minv:=9999.
 DMreset:=true, DMcount:=0
ENDINIT
EXEC
  vab:=abs(va-vb)
  vbc:=abs(vb-vc)
  vca:=abs(vc-va)

if t<0.005 then
    aux:=max(vab,vbc,vca)
    if aux>maxi then maxi:=aux endif
endif
signal:=max(vab,vbc,vca)/maxi

IF (signal<minv) THEN
    minv:=signal
ENDIF

if trigger=0 then
    if signal<0.75 AND DMreset=true then
      DMcount:=DMcount+1
      DMreset:=false
      WRITE1('(',DMcount,')  Degrade  Mode  en  t  =
',t,'s')
    endif
    if signal>0.8 AND DMreset=false then
      DMreset:=true
    endif
endif

if signal<0.6 then
    ta:=ta+timestep  -- acumula en el timer
    if ta>0.002 then -- timeout: potline trip
      if trigger=0 then tdisp:=t endif
      trigger:=1
      if prt=1 then
         WRITE('*** potline tripped at T=',tdisp)
         prt:=0
      endif
    endif
  else
    ta:=0.
  endif

IF (t=stoptime) THEN
  if (minv>0.75) then
```

```
     WRITE1('NO ACTUA PROT. LOWSYNC')
  endif
  if (minv<=0.75) AND (minv>0.61) then
     WRITE1('LOWSYNC V < 0.75 pu')
  endif
  if (minv<=0.61) AND (trigger=0) then
     WRITE1('LOWSYNC V < 0.60 pu')
  endif
  if (minv<=0.61) AND (trigger=1) then
     WRITE1('*** POTLINE TRIPPED AT T=',tdisp)
  endif
  if (DMcount>2) AND (trigger=0) then
     WRITE1('>>> Posible TTL trip')
  endif
  WRITE('----------------------------------------')
  WRITE('*** Vmin =', minv,' pu')
  WRITE1('VMIN = ',minv,' pu')
  WRITE('----------------------------------------')
ENDIF
ENDEXEC
ENDMODEL

USE LowSync AS LowSync
INPUT
  va:= M0002A
  vb:= M0003B
  vc:= M0004C
OUTPUT
  OUT:=signal
  DISP:=trigger
ENDUSE
RECORD
  DISP   AS DISP
  OUT    AS OUT
ENDMODELS
```