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TRANSIENT ANALYSIS OF A MEXICAN HYDRAULIC MICRO-GRID OF DISTRIBUTED GENERATION

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ABSTRACT
This paper discusses the transient analysis of a Mexican hydraulic micro-grid of distributed generation. The components of the hydraulic micro-grid are represented using EMTDC, and its graphical interface PSCAD.

KEY WORDS
Distributed generation, hydraulic micro-grid, transient analysis.

1. Introduction

Distributed Generation [1-3], is the electrical power generation based on the use of small electric plants, installed near to the loads. There is not a formal definition about Distributed Generation, one definition highly accepted is from IEEE [4]: "Distributed Generation means the electrical power generation using small installations, with respect to the conventional electric power generator plants; this kind of plants can be connected at any point of an power and energy system".

One of the widely used technologies in distributed generation is the mini-hydraulic generation, since the plants can be installed in specific points where the kinetic energy of small rivers or water falls can be exploited. Micro turbo-generators can supply of electrical energy to small towns, factories or can be connected to the electrical power system. The hydraulic turbo-generators are used, because the speed of the fluid through the turbine is relatively high in comparison to big hydroelectric central, this yields to the use of hydraulic turbines together with synchronous generators of smaller number of poles, and bigger work speed. The complete hydraulic system (micro-generator/turbine) has a smaller inertia due to its size and capacity.

In this contribution a Mexican micro-grid based on a hydraulic micro-generation is described and analyzed, illustrating its transient and steady state operation.

The study of the models and the representation in PSCAD/EMTDC [5] of this type of units falls within the conventional models used for the representation of large capacity hydroelectric plants. The mechanical and electrical parameters are adjusted for the modeling and representation of the model for the micro-hidraulic unit.

2. Mexican Micro-grid of Hydraulic Generation

The 6 MW Metlac micro-hydroelectric plant is located in the district of Chocamán, Santa Ana Atzacan and Ixtaczoquitlan, Veracruz, Mexico. It is interconnected with a thermoelectric plant to jointly feed the Cuauhtémoc Moctezuma brewery [6].

The hydraulic micro-generation plant is fed by the rivers Metlac, Tocuila and Sonso. It generates 1,600 KWh in low rain fall season and up to 5,000 KWh in the high rain fall season, with an annual average generation of 24,500 KWh. It also has auxiliary constructions as as bedrooms, service building (office, cellar and sanitariums), dining room and the auxiliary personnel's bathrooms and a house room. The Figure 1 shows the outline of the hydraulic system.

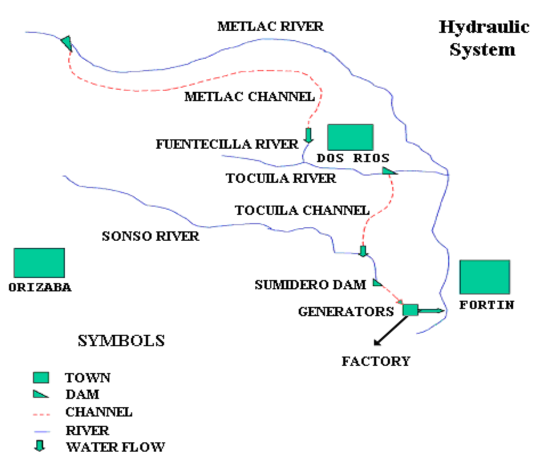


Fig. 1 Outline of the Metlac hydraulic system

The hydroelectric plant has the following components:

- *pressure pipeline:* two units, with capacity of 2 160 lps c/u, built of steel to the coal, with grill protection in the beginning of the pipeline, with diameters of 1.10 and 0.9 m, respectively, they have air purge devices and over-speed speed closing devices. The pipeline across a tunnel of 190 m long.
- *turbines:* three units, Voith, horizontal Francis , 2 160 lps, 900 rpm, 3 000 Hp, height of 125 m.
- *generators:* three units, Westinghouse, 2 500 KVA (2 000 KW), 6 900 V, 60 hertz, cooled by air.
- *control and protection board of the generators:* it consists of 5 sections, with switches in small volume of oil, protection of instantaneous high-current, voltage regulators, synchronization console and a bank of batteries with 2 loaders for control voltage.
- *voltage transformers:* four units, Westinghouse, single phase 6 900 to 16 600 V, 2 000 KVA c/u.
- *transmission lines:* two units, they have 2 switches, one of great volume of oil and another of small volume of oil; 3 threads 1/0 AWG, 14 Km long.

In the Figure 2 the single phase diagram of the mini-hydraulic Plant Metlac is illustrated.

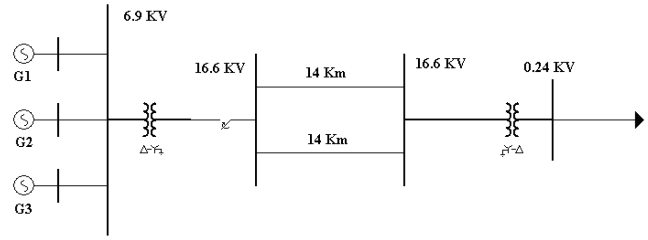


Fig. 2 Diagram of the Metlac plant

3. Case Study

The system of Figure 3 is used for the analysis of the hydraulic micro-grid under steady state and transient operation conditions, using PSCAD/EMTDC. Details of micro-grid parameters are given in Appendix A and of the generator controls in the Appendix B.

A three phase short circuit is assumed, since it involves considerable mechanical and electrical stresses. The behavior of the currents and voltages when the three phase fault takes place at the load terminals is analyzed.

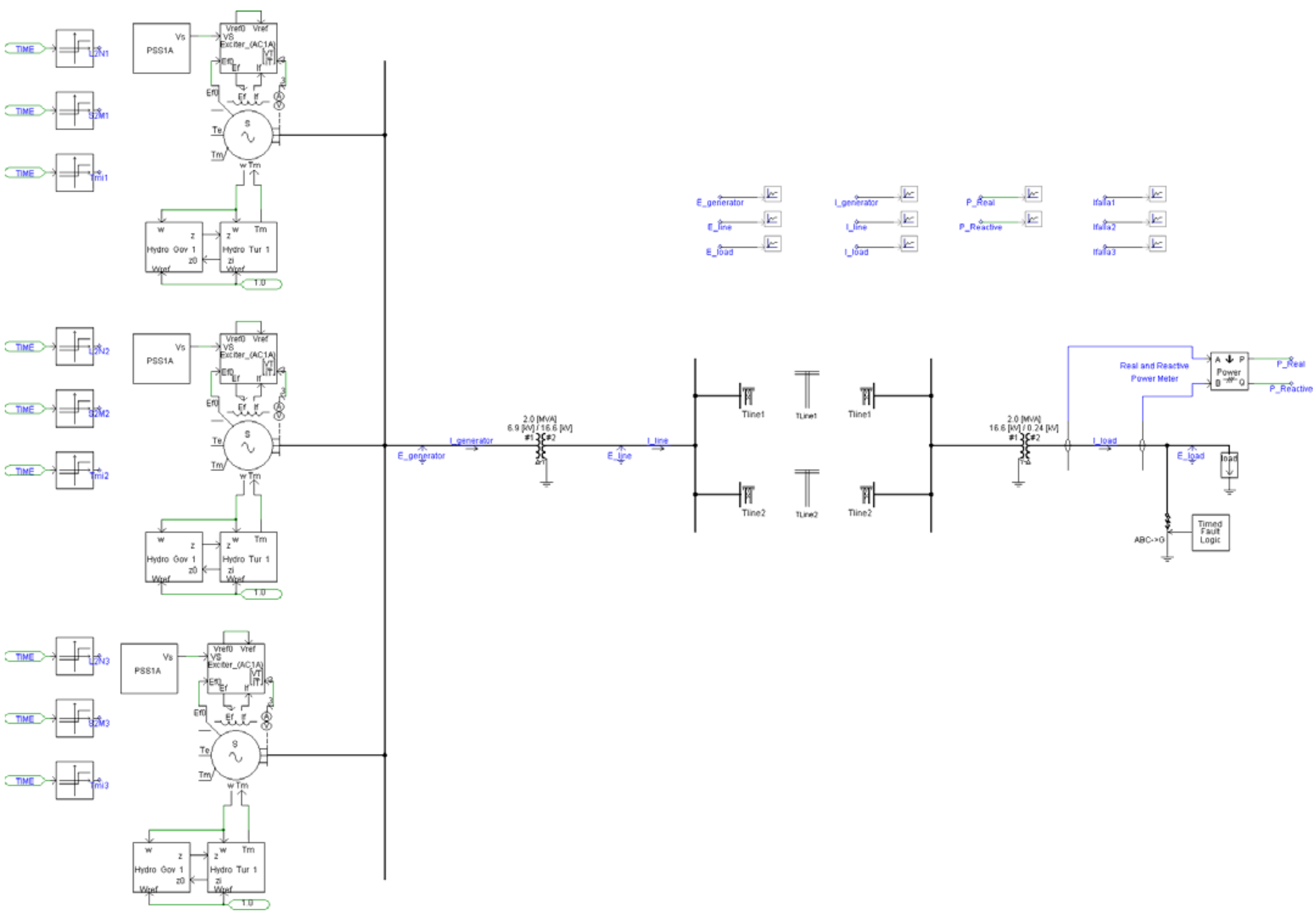
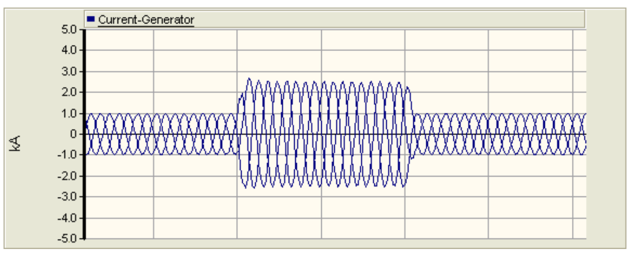


Fig. 3 PSCAD/EMTDC representation of the hydraulic micro-grid of generation.

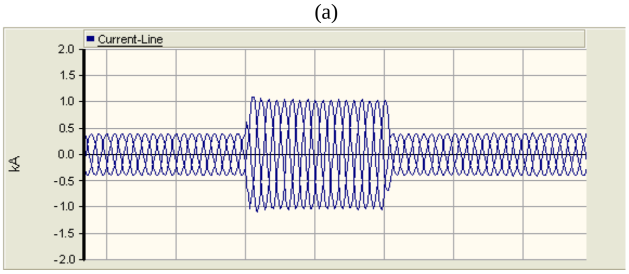
The three phase fault is applied at the load terminals after 3 seconds of simulation time, when the system is already operating in steady state; the fault is maintained for 0.1 seconds and removed afterwards.

The Figure 4 (a) illustrates the behavior of the currents at the generator terminals. It is observed that before the fault take place the currents have an amplitude of 1.0 kA, when the fault is present the current in each phase increases to 2.5 kA, remaining in that amplitude until the fault is removed; the phase current oscillates approximately for 0.04 seconds before returning to its pre-fault steady state.

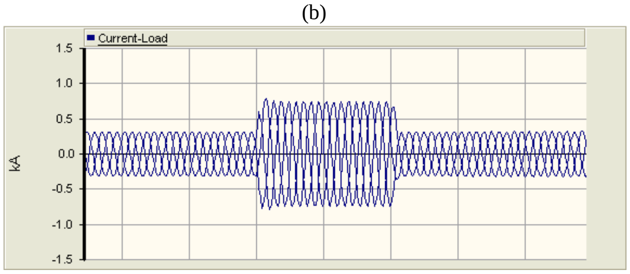
On the other hand, the currents in the load illustrated in the Figure 4 (c), have an amplitude in steady state of 0.29 kA. When the fault is applied to the system, the currents increase in amplitude to 0.75 kA. Once the fault is removed the phase currents experiment a transient for approximately 0.015 seconds before returning to their pre-fault steady state.



(a)



(b)



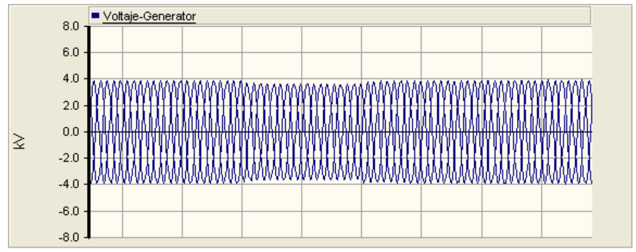
(c)

Fig. 4 Phase currents for a three phase fault at the load terminals. (a) generator stator currents, (b) distribution line currents, (c) load currents.

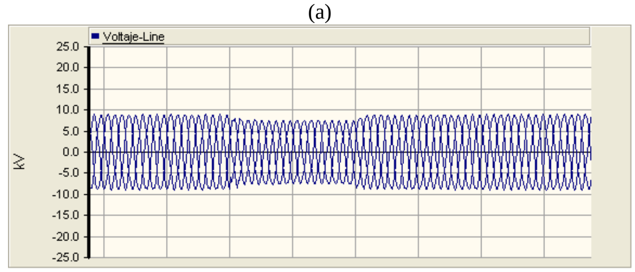
In the Figure 5 (a) the behavior of the voltages at the generator terminals is shown. These have an pre-fault amplitude of 3.9 kV. When the three phase fault take place the phase voltages fall to 3.75 kV. The voltages return to their steady state 0.015 seconds after the fault is removed.

The Figure 5 (b) shows the behavior of the phase voltages in the distribution line. These have an amplitude in steady state of 9.5 kV; the voltages decrease during the fault to 8.1 kV, and after the fault is removed the voltages reach their steady state behavior in approximately 0.015 seconds.

The Figure 5 (c) illustrates the behavior of the load voltages. They have a pre-fault amplitude of 0.13 kV, during the disturbance the phase voltages decrease to 0.06 kV, returning to the pre-fault steady state after 0.07 seconds of having removed the fault.



(a)



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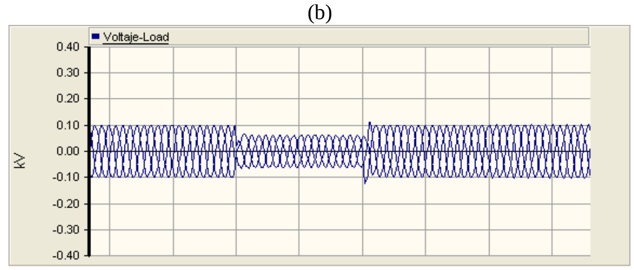

(c)

Fig. 5 Behavior of the phase voltages for a three phase fault at the load terminals. (a) generator terminal voltages, (b) distribution line voltages, (c) load voltages.

4. Conclusion

A practical micro-grid of hydraulic generation located in Metlac, Veracruz, México has been described; its dynamic behaviour analyzed and represented using PSCAD/EMTDC.

The transient response of the system was obtained and detailed for case of study consisting of a three phase fault applied at the generator terminals. The transient and steady state behaviour was analyzed at different locations of the hydraulic micro-grid of generation.

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References

[1] Ann Chambers, *Distributed Generation: A No Technical Guide*, PennWell, 2001.

[2] Anne-Marie Borbely and Jan F. Kreider, *Distributed Generation, The Power Paradigm for the New Millennium*, CRC PRESS, 2001.

[3] Roger C. Dugan, *Distributed Generation*, IEEE Industry Applications Magazine March/April 2002.

[4] *Dispersed Generation*. CIRED WG04, June 1999.

[5] Manitoba, HVDC Research Centre Inc. *PSCAD User's Guide*, , March 2003.

[6] [Online]. Available: *Http://www.conae.gob.mx/work/secciones/1171/imagenes/Ccmb2so.pdf*

Appendix A: Case Study Parameters

- *Synchronous micro-generator parameters*.

Terminal Real Power = 2 MW.
Terminal Reactive Power = 2.5 MVA.
Line Voltage = 6.9 KV.
Synchronous Speed = 900 rpm.
Frequency = 60 Hz.
Number of turbines = 1.
Inertia Constant = 1.7 seg.
Armature Resistance Ra = 0.002 p.u.
Armature Time Constant Ta = 0.332 seg.
Potier Reactance Xp = 0.130 p.u.
Unsaturated Reactance Xd = 0.920 p.u.
Unsaturated Transient Reactance Xd' = 0.920 p.u.
Unsaturated Sub-transient Reactance Xd'' = 0.220 p.u.
Unsaturated Reactance Xq = 0.510 p.u.
Unsaturated Transient Reactance Xq' = 0.228 p.u.
Unsaturated Sub-Transient Reactance Xq''= 0.290 p.u.
Air Gap Factor = 1.0.
Unsaturated Transient Time Tdo' = 5.2 seg.
Unsaturated Sub-transient Time Tdo'' = 0.029 seg.
Unsaturated Transient Time Tqo' = 0.85 seg.
Unsaturated Sub-transient Time(Tqo'' = 0.034 seg.

- *Three phase transformer parameters (T1):*

Reactive Power = 2.0 MVA.
Connection type = Δ-Y in lag.
Positive Sequence Leakage Reactance = 0.1 p.u.
Base Operation Frequency = 60 Hz.
Winding Voltage = 6.9 KV/16.6 KV.
Place Saturation on Winding = #1.
Air Core Reactance = 0.2 p.u.
Inrush Decay Time Constant = 1.0 seg.
Knee Voltage = 1.25 p.u.
Magnetizing Current = 1%.
Time to Release Flux Clipping = 0.1 seg.

- *Three phase transformer parameters (T2):*

Reactive Power = 2.0 MVA.
Connection type = Y-Δ-in lag.
Positive Sequence Leakage Reactance = 0.1 p.u.
Base Operation Frequency = 60 Hz.
Winding Voltage = 16.6 KV/ 0.24 KV.
Place Saturation on Winding = #1.
Air Core Reactance = 0.2 p.u.
Inrush Decay Time Constant = 1.0 seg.
Knee Voltage = 1.25 p.u.
Magnetizing Current = 1%.
Time to Release Flux Clipping = 0.1 seg.

- *Distribution line parameters.*

Voltage = 16.6 KV.
Steady state frequency = 60 Hz.
Length of line = 14 Km.
Number of equivalent conductor = 3.

- *Tower configuration and parameters, see Fig. 6*

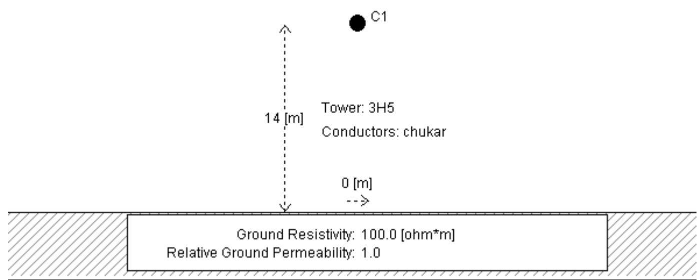

Fig. 6 Tower configuration and parameters.

Appendix B: Controller System Block Diagrams.

- *Non-Elastic Water Column without Surge Tank Turbine.*

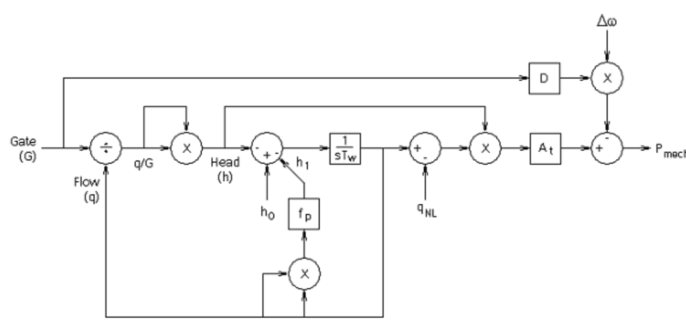

Fig. 7 Turbine Block Diagram.

Where:

A_t	Turbine Gain Factor Flow (1.0 p.u.).
f_p	Penstock Head Loss Coefficient (0.02 p.u.)
G	Gate Position (1.0 p.u.)

q Turbine Flow before reduction by deflector and relief valves (1.0 p.u.).
q_{NL} No load water flow (0.05 p.u.)
T_w Water Starting Time (0.0 sec).

- *Mechanical-Hydraulic Controls (Hydro Governor)*

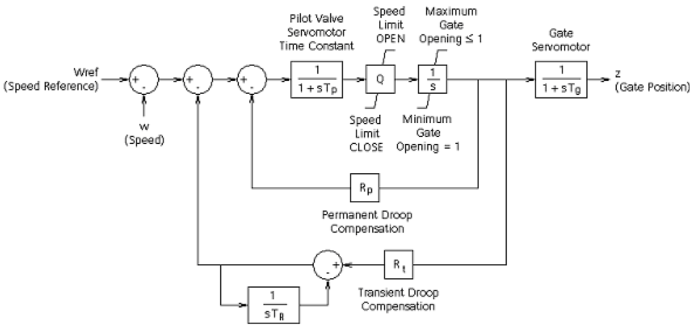

Fig. 8 Governor Block Diagram.

Where
Q Servo gain (5.0 p.u.)
Rp Permanent Droop (0.04 p.u.)
R_t Temporary Droop (0.40 p.u.)
T_g Main Servo Time Constant (0.5 sec)
T_p Pilot valve and servo motor time constant (0.05 sec)
T_R Reset or Dashpot Time Constant (5.0 sec)

- *IEEE Alternator Supplied Rectifier Excitation System*

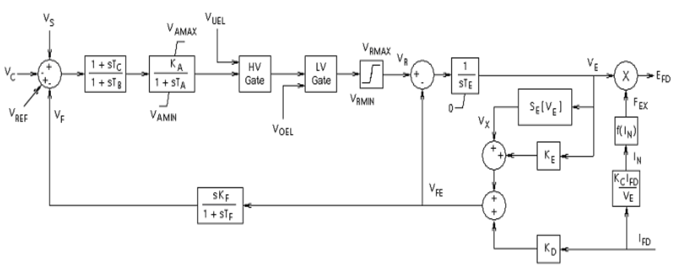

Fig. 9 Exciter Block Diagram.

Where
V_c Output of terminal voltage transducer and load compensation elements
V_{ref} Voltage regulator reference (2.76 kV)
V_s Combined power system stabilizer and discontinuous control output after limits or switching, as added with terminal voltage and reference signals
V_F Excitation system stabilizer output
V_{AMAX}, V_{AMIN} Maximum and minimum regulator output limits (V_{AMAX} = 14.5 p.u., V_{AMIN} = -14.5 p.u.)
K_A Voltage regulator gain (400.0 p.u.)
T_A, T_B, T_C Voltage regulator time constants (T_A = 0.02 sec, T_B = T_C =0.0 sec)
V_{UEL} Under-excitation limiter output (-1.0E10 p.u.)
V_{OEL} Over-excitation limiter output (1.0E10 p.u.)
V_{RMAX}, V_{RMIN} Maximum and minimum regulator output limits (V_{RMAX} = 6.03 p.u., V_{RMIN} = -5.43 p.u.)
V_R Voltage regulator output
V_{FE} Signal proportional to exciter field current (14.0 p.u.)
T_E Exciter time constant, integration rate associated with exciter control (0.80 sec)
V_E Exciter voltage back of commutating reactance (4.18 p.u.)
K_E Exciter constant related to self-excited field (1.0 p.u.)
K_D Demagnetizing factor, as a function of exciter alternator reactance (0.38 p.u.)
K_F Excitation control system stabilizer gain (0.03 p.u.)
V_X Signal proportional to exciter saturation
$S_E [V_E]$ Exciter saturation function value corresponding to the exciter voltage, V_E, back of commutation reactance (0.10 p.u.)
K_C Rectifier loading factor, proportional to commutation reactance (0.20 p.u.)
I_{FD} Synchronous machine field current
I_N Normalized exciter load current
F_{EX} Rectifier loading factor, a function of I_N
E_{FD} Exciter output voltage

- *Single Input Power System Stabilizer*

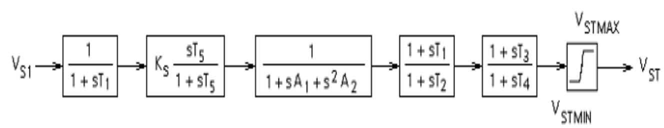

Fig. 10 Power System Stabilizer Block Diagram.

Where

A_1, A_2 Signal conditioning frequency filter constants (A_1= A_2 = 0.0)
K_S Gain (5.0 p.u.)
T_1, T_3 Lead time constants (T_1 = 0.0 sec, T_3 = 0.08 sec)
T_2, T_4 Lag compensating time constants (T_2 = 6.0 sec, T_4 = 0.01 sec)
T_5 Washout time constant (10.0 sec)
V_{S1} Input
V_{STMAX}, V_{STMIN} Maximum and minimum output limits (V_{STMAX} = 0.1 p.u. , V_{STMIN} = -0.1 p.u.)
V_{ST} Output