

"PTTI APPLICATIONS IN POWER UTILITIES".

by

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ABSTRACT

Present and potential applications of PTTI in power utilities are described.

The Hydro-Québec time dissemination system is presented and its characteristics are given. Current applications include power-frequency control systems, sequential-events recording and phase-angle measurement.

The paper presents the phase-angle measurement system and its importance as a monitoring device for an electric power utility and provides an example of recorded disturbance.

I. INTRODUCTION

Electric power systems are like human being: they cannot be stopped in order for us to carry out an examination of how they work. All analyses are therefore made on the "living fabric" as it were. In addition, power systems have a fast-moving "life style": they can fall "sick" (disturbance or even instability) within milliseconds and can "lose a limb" (local power failure) or "die" (general black-out) in a couple of seconds.

In analyzing this kind of behavior, time is crucial. The operating speed of electric grids is such that events follow on each other's heels and system analysts are faced with the arduous task of distinguishing between occurrences that are very close to each other in time.

A further complication is the size of modern power systems. So, although it is relatively easy to put a precise date on events that occur only microseconds apart in the same place, the same cannot be said when the events occur at distance of 1000 km or more apart.

This article takes a look at direct (simple dating of events) and indirect (conversion of a physical variable - angle or distance - into a time) time applications in the context of electric power systems.

II. SEQUENTIAL-EVENTS RECORDING AND OSCILLOGRAPHS

Broadly speaking, an electric power system can be said to consist of generators, transformers and lines. Switches are used to link these three types of component and to connect them with the loads. The switches are activated either for operations intended to add or remove a generator, a line or a load, or to rapidly isolate the part of the system affected when a fault occurs.

A. SEQUENTIAL-EVENTS RECORDING

An excellent way to monitor what is happening on the system is to date all the operations of these switches and of the devices used to activate them, especially protection relays. For example, if the sequential-events record shows that the overcurrent relay opened the switches connecting a transformer T to the rest of the system and that other switches then came into operation to remove a line, then there is a strong probability that the transformer T was affected by a fault which was cleared, but not without secondary effects. The transformer must therefore not be put back into service without a closer examination.

B. OSCILLOGRAPHS

Another valuable source of information is the oscillograph. This device records on paper all the different voltage and current waveforms which provide the information needed to confirm the occurrence of the fault and determine which phase of transformer T is involved. Usually the different curves are plotted side by side on the same sheet of paper in a given substation, which means that all the information is synchronous. To compare oscillograms coming from different places, therefore, there must be some means of resynchronization. An IRIG-B code, for example, can be used in one of the plots.

C. DATING ACCURACY

Both recording techniques above call for a standard time system accurate to the nearest millisecond. Considering the response times of the various protection relays (a few milliseconds) and the switchgear (a few 60 Hz cycles), this accuracy is quite suitable for distinguishing between recorded events or resynchronizing waveforms whose nominal period exceeds one millisecond.

III. VOLTAGE PHASE ANGLE

A. DEFINITION AND PURPOSE OF THE MEASUREMENT

A power system affected by a disturbance will "sneeze", loudly or softly, according to the cause, so that the type and waveform of the "sneeze" represent a very useful means of identifying the bug responsible.

Simplifying again, generators can be considered as masses with a given inertia, which are connected to each other and to the load by electrical springs. The balance between generation and load defines a stable rotational speed. When a disturbance occurs, these masses start to oscillate but, contrary to the classical model of a mass at the end of a spring, the synchronous nature of the generating units has the effect of making the restoring force of the electrical spring proportional to the sine of the elongation rather than to the elongation itself. Thus, if the elongation exceeds 90 degrees in the steady state, the restoring force decreases as the elongation increases and a loss of synchronism and pole slipping occur, causing a virtual voltage zero to appear. This is perceived by the system as a short circuit or fault.

Elongation is clearly a very critical parameter for electric power systems. In practice, it takes the form of the phase angle that exists between the voltage vectors at two points on the system. In the case of a line under steady-state conditions, the equation is:

$$P = \frac{E_i E_j}{X_{ij}} \sin \delta_{ij}$$

where E_i et E_j represent the voltages at the line terminals, X_{ij} the line reactance and δ_{ij} the voltage phase angle.

Any disturbance causes an oscillation of the masses present in the system and the curves obtained at different points on that system constitute a characteristic "signature" of the event. With signature analysis, it is possible to understand the system's behavior during disturbances, however minor, and to ascertain whether it is normal so that, if not, corrective measures can be taken to avoid more serious consequences. Measurement of this parameter can also contribute to the development of manual and automatic controls for the power system and numerous applications have already been suggested [1].

B. MEASURING TECHNIQUE AND REQUIRED ACCURACY

Since the voltage is almost periodic, the easiest measuring technique is to simply convert the phase angle into a time interval, such as that between the zero crossing of the voltage at the two line ends.

Historically[2], initial attempts to do this consisted in bringing the voltage waveform (or a square wave synchronous with the zero crossings) from line end A to line end B and measuring the angular displacement at B. Unfortunately, the propagation time from A to B introduces an error which, in practice is of the same order as the value to be measured. This is why the research team elected to create local reference points at A and B that are synchronous [3,4]. This means that the local angle can be measured at each extremity by converting it into a time interval and transmitting the data to a common point where the voltage phase angle between the two line ends can then be obtained by subtraction.

The accuracy needed for this operation is of the order of the electrical degree, which at 60 Hz corresponds to a time accuracy of $\pm 40 \mu\text{s}$. At each measuring point, therefore, a clock must be installed and connected to a time dissemination system to ensure that its synchronism with the other is better than $40 \mu\text{s}$.

Various practical problems affect the measuring accuracy [5]. The presence of noise and harmonics alters the position of the zero-crossings. Filters can be used but only with caution [6], so that they do not unduly limit the passband or introduce excessive static or dynamic angle errors. In the case of postmortem analysis, the absence of filters make it easier to distinguish events such as harmonic resonances, for instance.

IV. FAULT LOCATION

Faults can be located [7] on a line by measuring the time between the arrival of the two traveling voltage waves generated by the fault at the two line ends.

Bonneville Power Authority (BPA) has developed a system they have baptized "Microtime" for synchronizing clocks using the microwave telecommunications network. A dedicated channel in the baseband is used, replacing several standard telephone lines.

In the fault-location context, distances are converted into times, the required accuracy being that which allows a distinction to be made between two transmission towers typically some 300 m apart. The required synchronization accuracy is therefore $1 \mu\text{s}$.

V. POWER-FREQUENCY CONTROL

Power-frequency control is related to the fact that the balance between load and generation defines the system frequency. The system frequency must therefore be maintained at the generation level, raising the latter if the frequency drops below 60 Hz and lowering it otherwise. Furthermore, in the view of the fact that many utilities producing electric energy transmit it over the same high-voltage grid, energy exchanges between utilities must be effected by pushing more or less energy on the system, according to needs.

Efficient management is therefore essential to ensure that at any given moment, utilities wanting to sell generate more, while those wanting to buy generate less [8].

A common time scale with an accuracy of a few minutes is obviously needed in order to define the start and end of these periods of energy exchange.

Another requirement is to keep the system frequency at its nominal value from minute to minute. At Hydro-Québec, this is done by means of a standard time system incorporated in the automatic power-frequency control. The latter is used for precision measurement of the power system frequency error and, according to the error value, acts on some of the machines in operation in order to reduce the frequency error to zero. Another function, secondary perhaps but most useful for time dissemination, is to keep the time error between a 60-Hz clock connected to the electric grid and the standard time system clock as close to zero as possible.

VI. HYDRO-QUÉBEC'S STANDARD TIME SYSTEM[9]

A. PRINCIPLE OF OPERATION

As shown in Fig. 1, a time code is sent from a master clock to the various points of use via Hydro-Québec's private telecommunication network. A modified IRIG-B code is used to overcome frequency error problems inherent in analog microwave units [10]. Slave clocks allow the number of telecommunication links to be minimized. At each substation, a standard IRIG-B code is reconstructed so that commercial time code readers can be used. A mobile clock with a rubidium frequency standard allows the propagation times on the microwave network to be calibrated.

B. MASTER CLOCK

The master clock comprises a rubidium frequency standard feeding two time accumulators (see Fig. 2). A third clock is synchronized on a GOES receiver. An automatic changeover switch detects errors in synchronism between the three clocks that exceed $\pm 250 \mu\text{s}$, checks that the time codes

generated by the clock are identical and make a majority decision as to which clock should send the code to the power system. The clocks are powered from a 110-V AC and a 48-V DC supply.

C. SLAVE CLOCKS (TYPE B)

As may be seen in Fig. 3, the slave clocks can be synchronized and have a correction mechanism allowing them to compensate for the signal propagation time from the master clock and, also, for internal time delay. In the absence of an input code, they continue to send their output to the user, introducing corrections for any internal quartz drift calculated when the synchronization code was present.

In this way, when the synchronization channel between a slave clock and the master clock is lost, everything transpires as if the secondary clock has just been synchronized and its quartz recently adjusted. The latter point is extremely significant in the case of systems that claim to be virtually maintenance-free.

These clock are powered from batteries (24 V DC or 48 V DC) of the microwave repeater or telephone exchange where they are installed.

They generate a standard IRIG-B code for local use and a modified one for remote use. A range of 8 to 24 isolated outputs is provided for.

D. LOCAL DISTRIBUTORS

The local distributors shown in Fig. 4 are used to restore a standard IRIG-B code from the modified code they receive. Their outputs drop to zero when the input code disappears.

They operate on a power supply of 24, 48 or 129 V DC and offer two to sixteen IRIG-B isolated outputs.

VII. HYDRO-QUÉBEC'S VOLTAGE PHASE ANGLE MEASUREMENT SYSTEM

Hydro-Québec's voltage angle measurement system uses the standard time system describe above. However, the points where the angle is measured are connected directly to the master clock. Each measuring unit comprises a slave clock (type C) with a rubidium frequency standard as its internal oscillator and optimized software designed to take advantage of the excellent medium-term stability offered by this oscillator. Figure 5 shows a typical curve of the time error recorded at Arnaud substation over a one-month period.

A. BLOCK DIAGRAM

The third generation of Hydro-Québec's phase angle measurement system comprises four measurement points, three on the Hydro-Québec side (Boucherville, Arnaud, and LG 2 substations) and one on the American side (Châteauguay substation). The data are sent to IREQ for processing via 9600-bps links. The central processing unit is a multi-task, multi-user minicomputer, HP 1000-A-900.

B. MEASURING-UNIT SPECIFICATIONS(Fig. 6)

The measuring unit reads the voltage phase angle once every cycle (the older generations, still in operation, take 30 readings per second) and also measures the positive and negative peak value of the three phases of a 735-kV line. If the voltage drops below 0.2 p.u., the unit changes its reference phase. It monitors up to six lines in each substation and selects one of the lines that is in phase for the measurement, so as to reject any line no longer connected to the substation bus.

The measuring unit has passed the IEEE 472-1975 surge withstand capability test. It is supplied simultaneously from 100-V AC and 129-V DC sources so as to avoid interruptions.

C. CURVES

Figure 7 shows the various curves plotted during a generation loss of 1500 MW at Churchill Falls as the result of a transformer fault. This figure shows quite clearly the effects of the event on the voltages at the various measurement points, on the LG 2-Boucherville and Arnaud-Boucherville phase angles, and on the Hydro-Québec system frequency and on the local phase of the American system (the derivative of the latter curve gives the frequency error of the American system).

VIII. CONCLUSION

Electric power systems need a common time scale at the various generating stations and substations on the high-voltage transmission grid. Some applications of precise time measurement make a direct use of time (dating of events) while others use time indirectly by converting the value measured (angle or distance) into a time interval.

The accuracy required varies from 1 ms for direct applications to 1 μ s for indirect applications.

The equipment must be maintenance-free and not require the presence of an operator, even after a power failure. It must be designed to operate properly in such strongly disturbed electromagnetic environments as high-voltage substations and to run on the battery voltage available there, even on two sources in some critical circumstances. Finally, it must be inexpensive.

It has been shown that existing time dissemination systems that meet the 1 ms and 40 μ s accuracy using standard communication channels are applicable on a wide basis. Microsecond accuracy in all substations calls for synchronization by satellite (GPS or other) [11].

IX. ACKNOWLEDGMENTS

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REFERENCES

- [1] P. Bonanomi, "Phase Angle Measurements with Synchronized Clocks - Principle and Applications," Presented at the IEEE PES Summer Meeting, Portland, Oregon, July 26-31, 1981. IEEE paper 81 SM 405-0.
- [2] L. Masson, "Mesure du décalage angulaire entre deux points du réseau," Hydro-Québec internal report No 6853, Feb. 25, 1968.
- [3] G. Missout, P. Girard, "Measurement of the Bus Voltage Angle between Montréal and Sept-Îles," IEEE Trans., Vol. PAS-99, No 2, p. 536-539, March-April 1980.
- [4] G. Missout, J. Béland, G. Bédard, Y. Lafleur, "Dynamic Measurement of the Absolute Voltage Angle on Long Transmission Lines," IEEE Trans., Vol. PAS-100, No 11, 1981, p. 4428.
- [5] A. G. Phadke, J. S. Thorp, M. G. Adamiak, "A New Measurement Technique for Tracking Voltage Phasors, Local System Frequency, and Rate of Change of Frequency," IEEE Trans., Vol. PAS-102, No. 5, May 1983.
- [6] D. Hansen, C. Dalpiaz, "Real Time Digital Encoding and Telemetry of Key Power System Transient Quantities," Western Protective Relay Conference, Oct. 23-25, 1984, Spokane, Washington.
- [7] D.C. Erickson, J.N. Andres, "Automatic Fault Location Using Microtime.," BPA document No AFL-100-01 May 25, 1982.
- [8] Natham Cohn, "Power System Time and Frequency," Leed and Northrup Tech. J. No 7, pp. 3-11, 1969.
- [9] G. Missout, J. Béland, G. Bédard, P. Bussièeres, "Study of Time Dissemination Methods Used on an Electric Power System with Particular Reference to Hydro-Québec," IEEE Trans. Vol. PAS-103, No 4, April 1984, pp 861-868.
- [10] G. Missout, W. Lefrançois, L. Laroche, "Time Dissemination in the Hydro-Québec Network," Proceeding of the 11th Precise Time and Time interval (PTTI) application and Planning Meeting, 27-29 Nov. 1979, NASA conf. Publication 2129, p.343.
- [11] J. Esztergalyos, D. C. Erickson, J. N. Andres, "The Application of Synchronous Clocks for Power System Fault Location, Control and Protection," Presented to the Seminar on the uses of precise time and frequency measurement in electrical systems, Nov. 5-6, 1985, Western Area Power Administration, Loveland, Colorado.

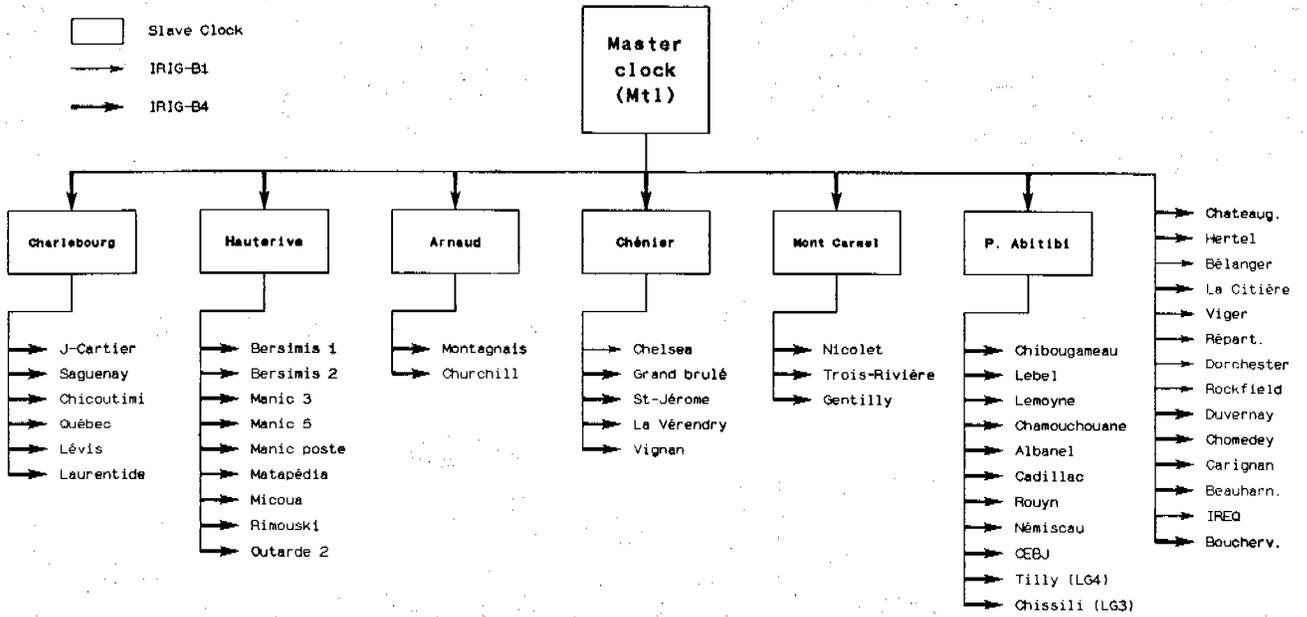


Figure 1 Hydro-Québec's Time Dissemination System.

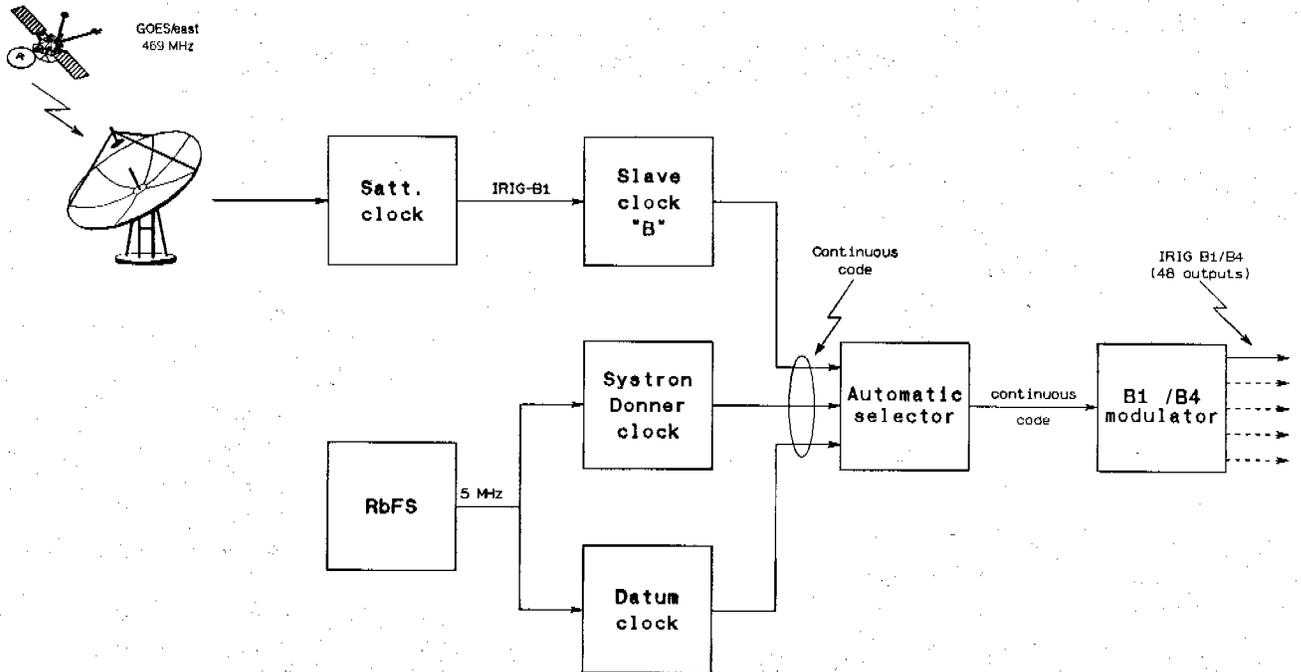


Figure 2 Block Diagram of Master Clock

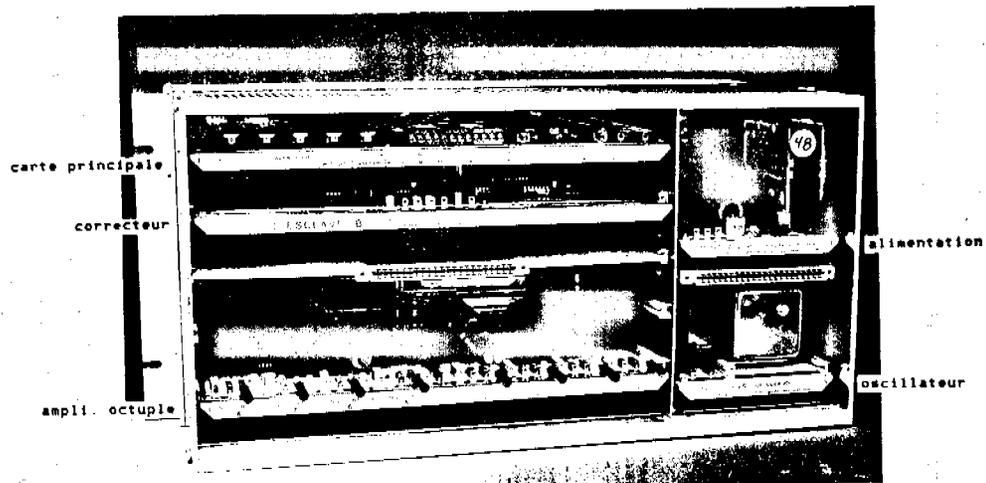


Figure 3 Photograph of Slave Clock (type B)

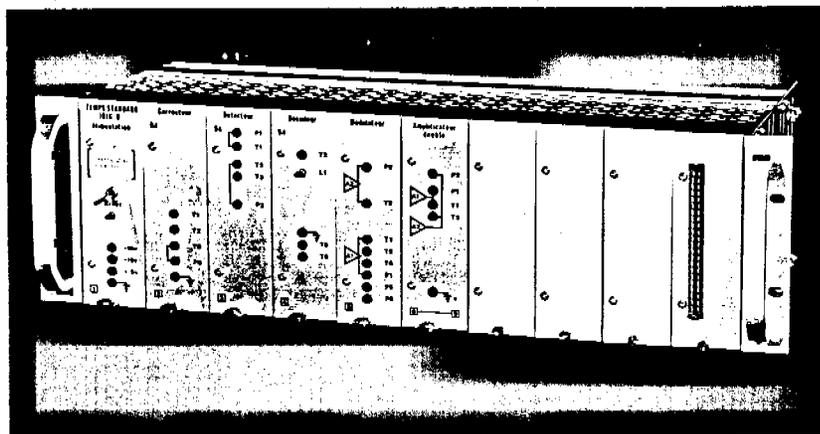


Figure 4 Photograph of Local Distributor

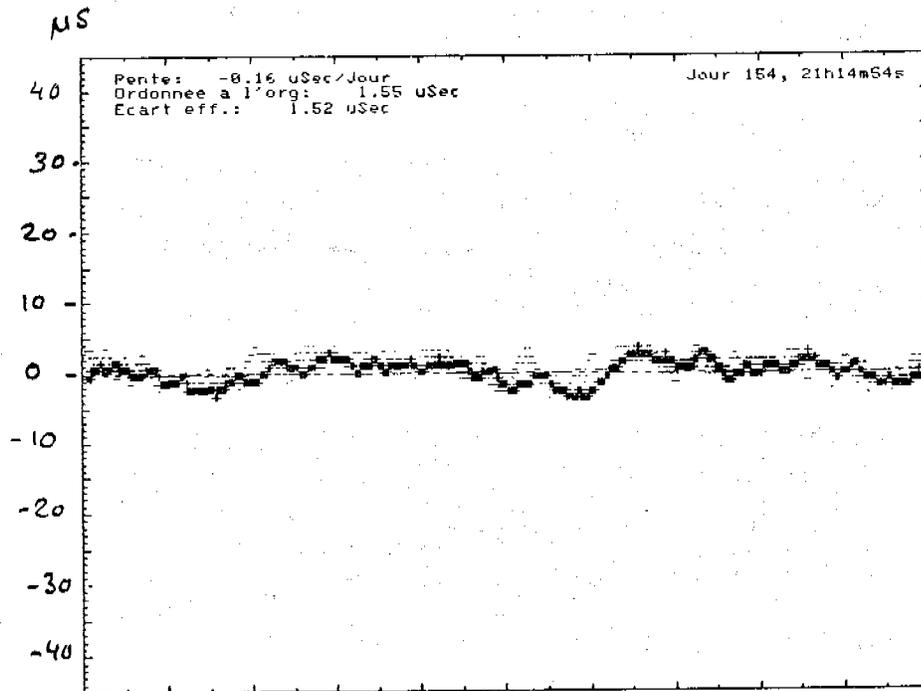


Figure 5 Time synchronization error for the Arnaud unit.

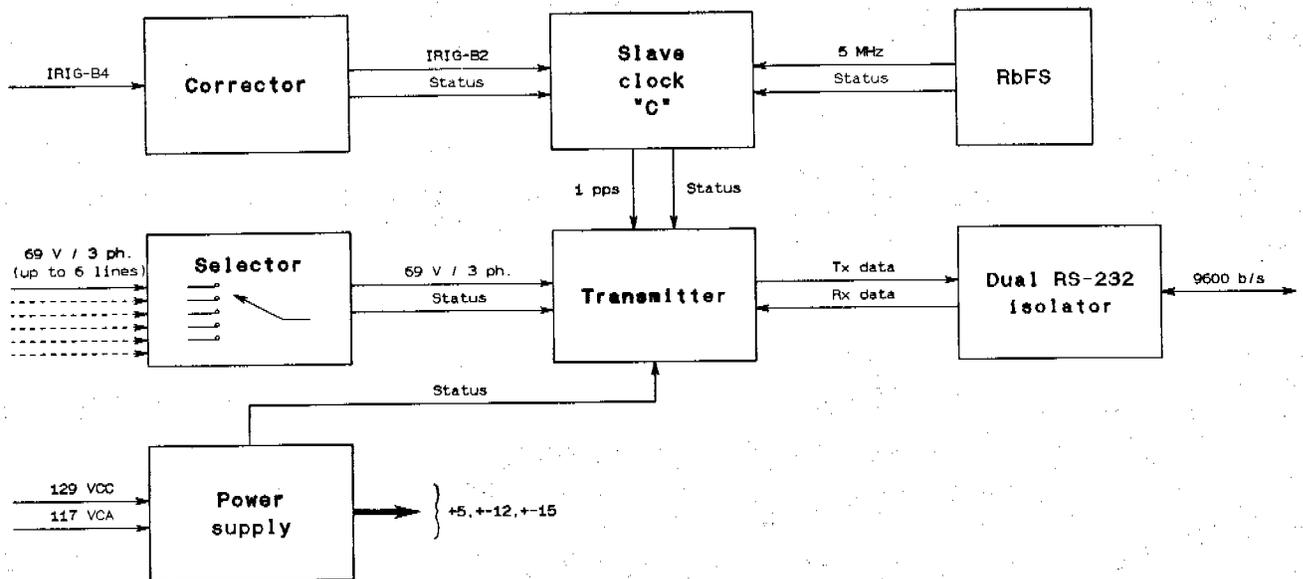


Figure 6 Block Diagram of Voltage Phase angle Measuring Unit

*** IREQ ***

ANGLES RELATIFS, ANGLE ABSOLU, FREQUENCE & TENSIONS CRETE A CRETE
 Ang. rel.: ARN-BDU et LG2-BDU; Ang. abs.: CHAT; Freq.: DOU; Tensions C a C: 4 postes.
 Echelles: TENSIONS= 1.0 P.U./Div, ANG. ABS= 25 Deg./Div, ANG. REL= 5 Deg./Div, FREQ = 0.5 Hz/Div.
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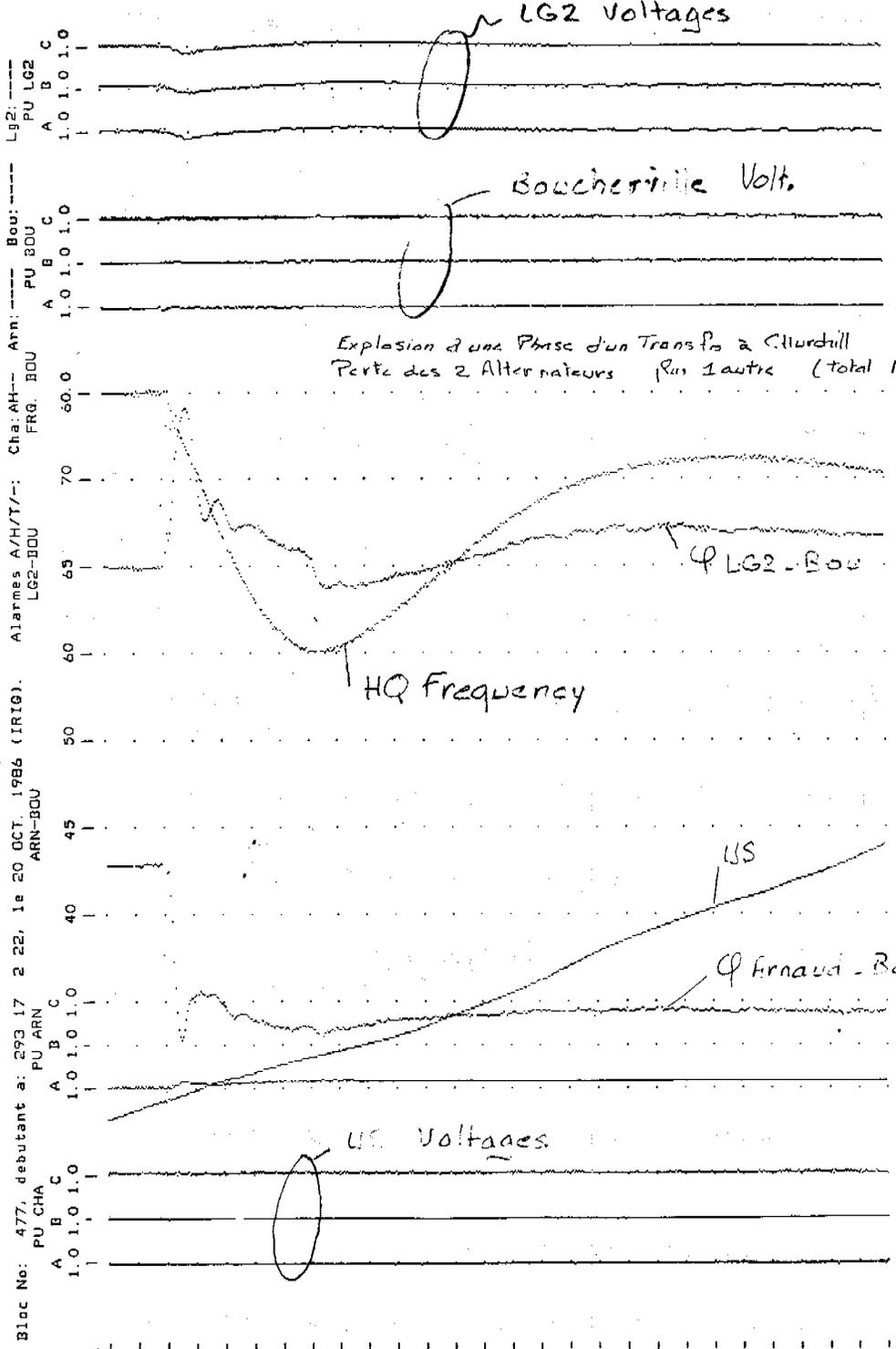


Figure 7 Output of the Voltage Phase Angle System for a 1500 MW Generation Loss