TRANSIENT STUDIES OF THE STATIC VAR COMPENSATOR OF SAN LORENZO - PARAGUAY

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Abstract - **There were several operational problems with the *Static VAR Compensator of San Lorenzo.* These problems are related to the explosion of several Current Transformers - CT's - and, of a pole of the circuit breaker of Filter 4. It is objective of this paper to carry out a preliminary analysis of the probable reasons responsible for these problems, and if possible, to suggest some corrective measures to solve them.**

Keywords: Modeling a Static VAR Compensator, Insulation Coordination, Maintenance and Failure Analyses

I. CONFIGURATIONS OF THE SAN LORENZO STATIC VAR COMPENSATOR

The *Static VAR Compensator of San Lorenzo* is a group of *5* capacitor banks switched by electronic devices, able of supplying or of absorbing reactive power according to the. power system needs. This permits a great flexibility on the controlling of the voltage in the *Metropolitan System Main Bus.*

The filters, with rated voltage of *100 kV* and rated power capacity of *50,7 MVAr* in *50 Hz* are connected in a wye insulated way. Its insulation level is of *185-450 kV*. The reclosing time is *110* seconds and, when considering a trapped voltage *75 kV*, the discharge time is *300* seconds.

The following data are related to the main component of the *Static VAR Compensator of San Lorenzo.*

√ *Capacitors:* - In each branch, there are *8* series capacitor banks, each with *4* parallel capacitive elements, manufactured according to *IEC-871-1*. Each capacitor presents *16.2 μF, 50 Hz, 7.2 kV* and *37 A*. Therefore, each filter branch presents a capacitance of *8.1 μF*, a rated voltage of *57.6 kV* and a rated current of *148 A*. Considering, according to *Fig 2*, *2* branches per phase, the equivalent capacitance per phase is *16.2 μF*.

√*Reactors*: - Air core, with an inductance of *68,02 μH* in the nominal tap. The reactors present a *Voltage Class* of *72,5 kV*, a *Basic Insulation Level* of *350 kV* and a rated current, in *50 Hz*, of *262 A*. The thermal withstanding capacity is of *1 kA, 1 second*, with a maximum peak current of *2,5 kA*. During steady state the current limit, including harmonics, is *309 A*. They are *Class B* insulated, and manufactured according to the requests stated in *IEC-289-1988*.

√*Current Transformers - CT's:* - The CT's present an *Insulation Level* of *72,5 kV*, a rated frequency of *50 Hz*, a power system withstanding voltage of *140 kV*, for *1* minute, and a *Basic Insulation Level* of *325 kV*. The thermal withstanding capacity is of *22-44 kA, 1 second*, with a maximum peak current of *55-110 kA*. They were manufactured according to *IEC-381*.

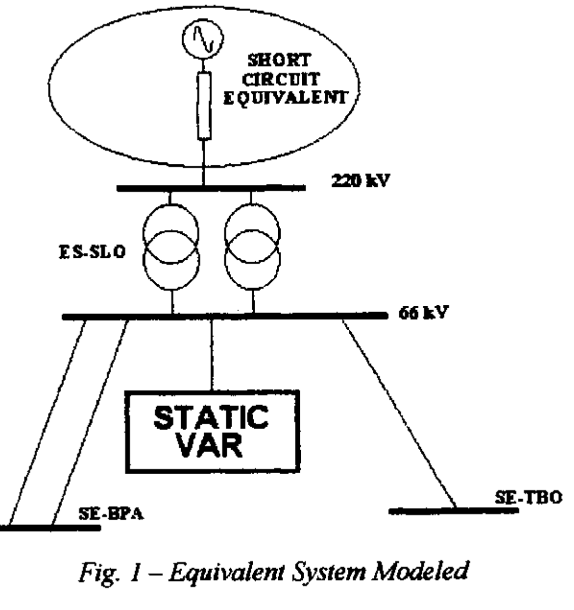

Fig. 1 – Equivalent System Modeled

A draft of the equivalent modeled system and also the connection of the filters is shown in the *Fig. 1* and *Fig 2*. Each capacitor branch, as previously stated is represented. There are two configurations; the first composed by the filters *1*, *2* and *3*, the second by the filters *4* and *5*. The draft also shows the position of the corresponding *CT's*.

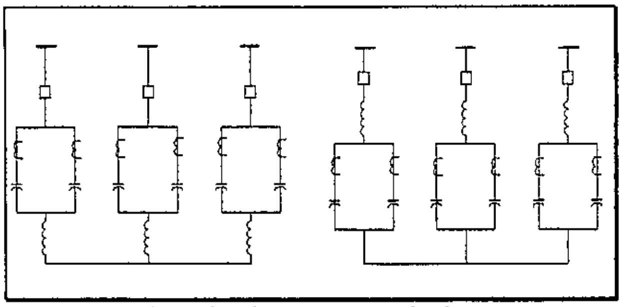

Fig.2 Filters Configurations of the Static VAr Compensator of San - Lorenzo

II. ANALYSIS OF THE PROBLEM

To perform the analysis of the problem it was observed the operation record of the equipment. Considering this, it was noticed the insulation degradation of the some of then -Variation of *the Tan δ*, a common practice in maintenance. To find some reason for this degradation, simulations of the transient behavior of the system were carried out by means of the software *ATP*.

II.1 STUDY OF THE FILTER SWITCH OFF

Explosions of *CT's* were registered during the switch off of the *Filter 4*. Due to this, the first study aimed at this phenomenon, i.e., to verify the stresses to which the *CT's* were submitted.

To this study, the system was fully modeled and the filters represented with the highest possible accuracy, including the modeling of stray capacitances of the *CT's*, of the circuit breakers, etc. The power system was modeled by an equivalent connected to the *66 kV* bar, as shown in *Fig 1*. The parameters of this equivalent were obtained short circuit studies.

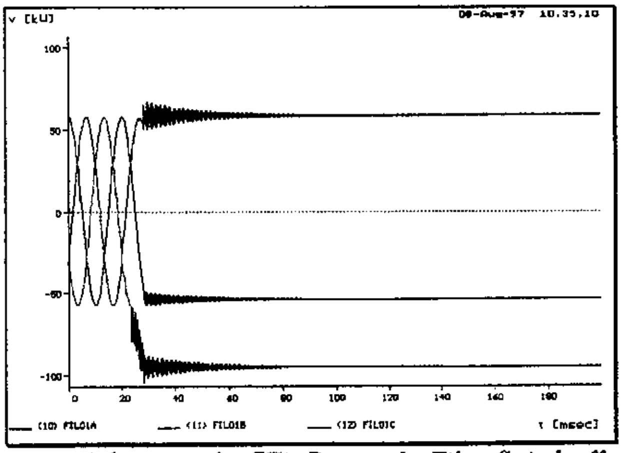

Fig 3. Voltages in the CT's During the Filter Switch off

After the switch off of the filter, exists in the *CT's* terminals an overvoltage associated to the dispersion in the opening time of the contacts of the breaker and to the configuration of the filter – wye insulated. Due to the presence of a residual charging in the capacitors, the voltage in the *CT's* terminals can reach the order of *100 kV* in one of the phases, as shown in *Fig. 3*. Considering that for an applied voltage of *75 kV* the discharge time of the capacitors is around *300 seconds*, the time under this voltage stress will be higher. This can age the equipment insulation.

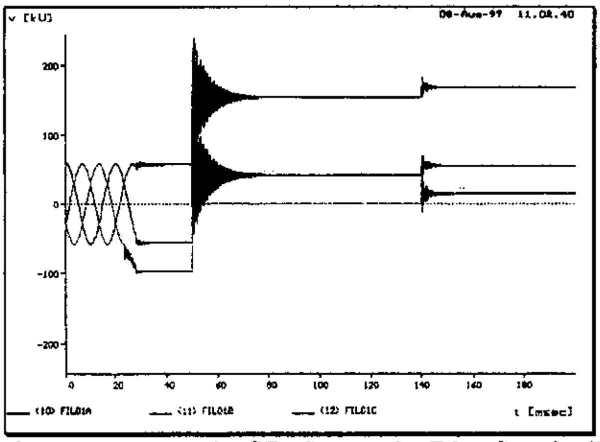

Fig 4. Voltages in the CT's During the Filter Switch off After a Discharge on the CT with the Highest Voltage

It was also verified oscillations of high frequency, whose existence in the real situation should be checked, since they could be associated to the adopted modeling degree.

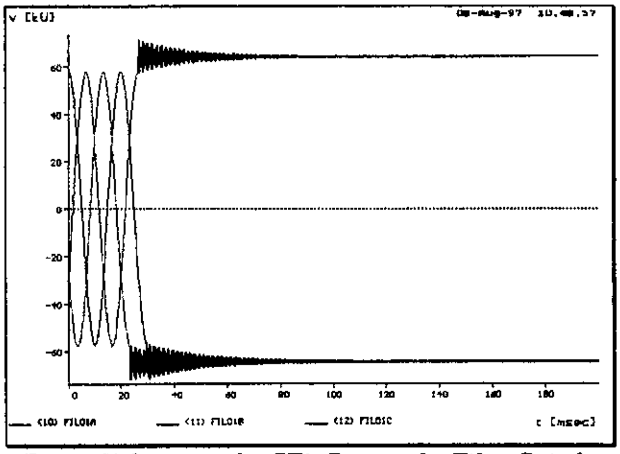

Fig.5 - Voltages in the CT's During the Filter Switch off – Grounded Neutral Capacitors Bank

Later on, for the *CT* submitted to the highest voltage - *Phase B* – it was modeled an insulation failure, as stated in *Fig. 4* – for a time *t=50ms*. This was decided, after having found signs of discharges in the *CT's* terminals, and considering that they could have an origin associated to the degradation of the insulation.

The voltage stress of the faulted terminal is insignificant. In the other two phases, the voltage is increased of the value of the *t*- voltage. This can be also observed when analyzing the equivalent circuit.

When the extinguishing of the power arcing - *t=140 ms* - the voltages will be higher than previously due to the increment resulted of the filter capacitors recharging through the stray capacitances of the circuit.

III. CORRECTIVE PROCEDURES

To avoid the degradation *CT's*, the following corrective procedures can be taken:

√- Overvoltage elimination.
√- To use another *CT's.*
√- To modify the filters configuration

Among the above procedures, the second does not need complementary studies – it is only necessary to choose *CT's* able to withstand the voltage stresses. The third one depends only on the possibility of doing the necessary equipment connections.

Considering this the following studies aiming at the overvoltage elimination must be carried out.

IV. OVERVOLTAGE ELIMINATION

IV.1 GROUNDING OF THE FILTER NEUTRAL

With this procedure are avoided overvoltages in the *CT's* during the switching off operation of the banks. The voltage level at the *CT's* will be the peak value of the source voltage before the circuit breaker opening, as shown in *Fig 5.*

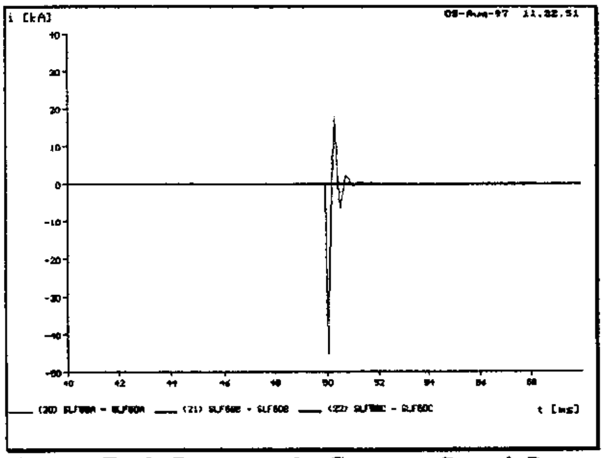

Fig 6 – Fault Current in the Capacitor Branch Due to a CT Insulation Failure – Filters 4 and 5 Grounded

It should be observed that a phase to ground failure - discharge through the *CT* insulation - during switching off results in a high peak fault current that can damage the capacitor bank – *Fig 6.* However the probability of occurrence of this fault is low due to the existence of lower voltage stresses in this configuration.

In the case of neutral grounded *Filters 1, 2* and *3*, the reactors, as can be seen in *Fig. 7*, limit the fault current.

To finish this study, it is necessary to verify the influence of short circuit currents in incoming lines or close bars to the *San Lorenzo* substation - *SE-SLO.* The filters are tuned for third harmonic currents; therefore they present null impedance for these currents, providing a path to the circulation of sequence zero currents. In this way, it should be verified if the filters can withstand these stresses.

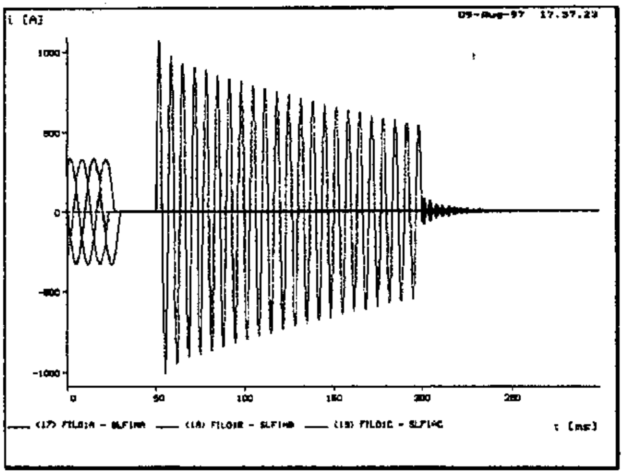

Fig 7 – Fault Current in the Capacitor Branch Due to a CT Insulation Failure – Filters 1,2 and 3 Grounded

To carry out this study, the equivalent *220 kV* system to *SE - SLO,* and the transmission lines connected to the substations Barrio Parque, *SE-BPA,* and Tres Bocas, *SE-TBO*, were modeled. The remaining part of the system was modeled by a short circuit equivalent, since more distant short circuits present smaller consequences.

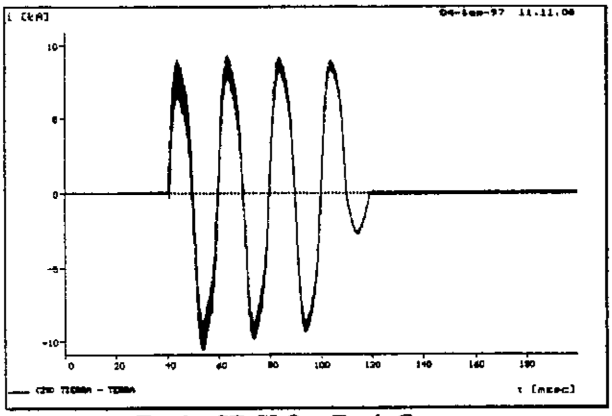

Fig 8 - SE-SLO – Fault Current

For *SE – SLO* and *SE – TBO - 66 kV* - bus bars, phase to ground faults were simulated. The fault current, for a short circuit in the *SE - SLO*, is smaller than the previous value, due to its limitation by the reactor of the filters, as shown *Fig 8.*

The fault current in the case of a short circuit in the *66 kV* bus bar of the *SE-TBO* is still smaller once *LT 66 kV SLO-TBO*, as shown by *Fig 9* limits it.

In both cases, the fault current return is in the following way , as shown *Fig. 10* and *11:*

√- The fundamental component circulates through the *ES-SLO* transformer.
√- The third harmonic component circulates through the filters.

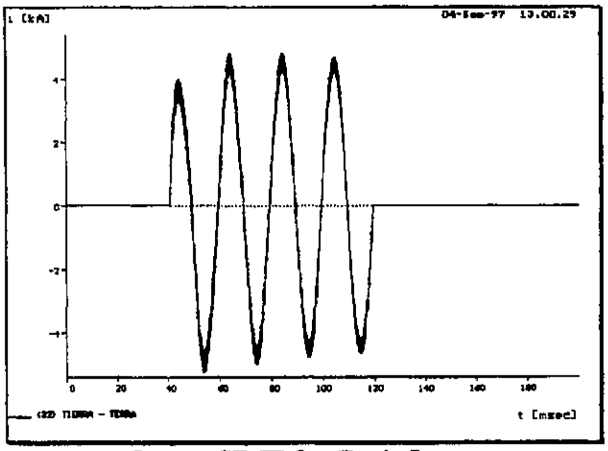

Fig. 9 - SE-TBO – Fault Current

This occurs up to the moment of the fault elimination. Then the third harmonic current remains circulating through the *SE-SLO* transformer and the filter.

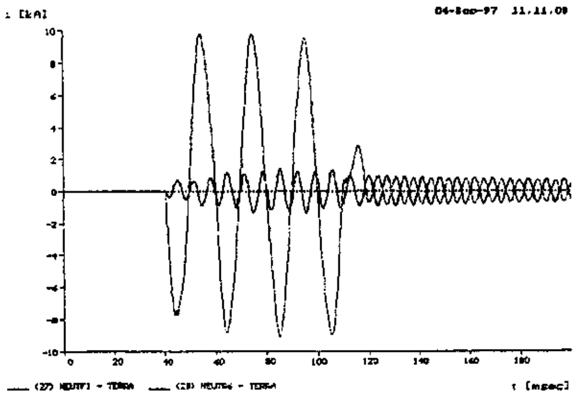

Fig. 10 – Current Circulating through the Filter and Transformer in SE-SLO

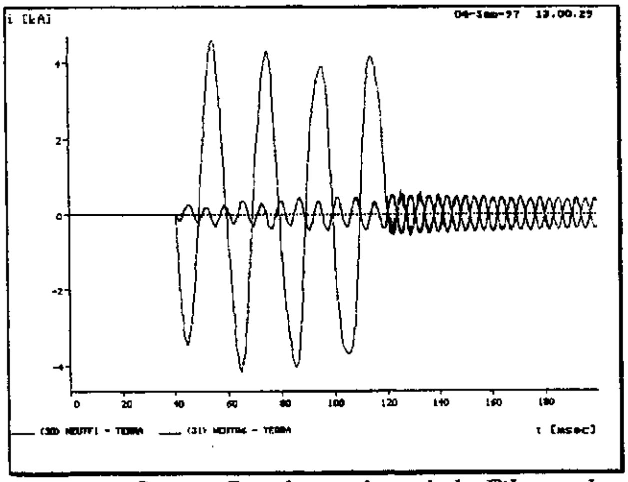

Fig. 11 – Current Circulating through the Filter and Transformer in SE-TBO

In the filter bus connection, for phase to ground faults in the *66 kV* bus bar of *SE-SLO* and of *SE-TBO*, there are currents due to the circulation of third harmonic components, as shown respectively in *Fig. 12* and *Fig.13*.

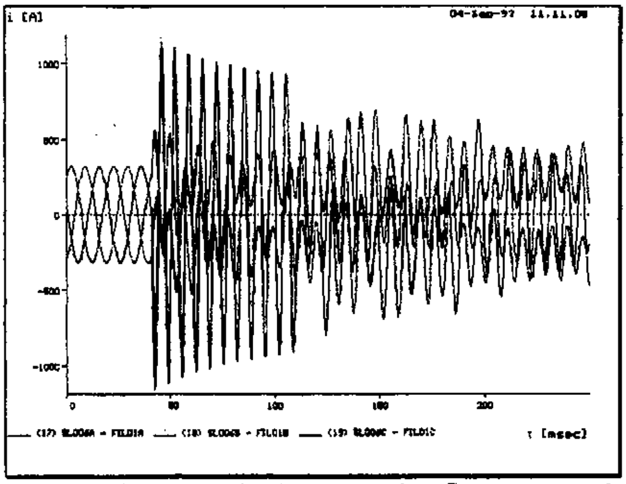

Fig. 12 – Current in the Entrance - Bus Connection - of the Filter of SE-SLO

IV.2 Installation of Surge Arresters

For the accomplishment of this study, a type *EXLIM Q 60 kV* surge arrester was considered. *Table I* shows the *Residual Voltage x Discharge Time* characteristic modeled.

The power frequency withstand capability of these surge arrester considered in this study is:

√- *1 A – 69 kV* for *1 second.*
√- *0.1 A – 66 kV* for *10 seconds.*

Table I - Residual Voltage x Discharge Time Characteristic

Discharge Current [kA]	Residual Voltage [kV]
0.01	111.22
0.1	124.50
0.3	129.48
1	137.78
4	151.06
10	166.00
20	184.26
60	234.06

The surge arrester attenuates the overvoltage during the switching off. However, as it presents a high threshold voltage, the contribution of the surge arrester is limited to the first voltage spike, as shown in *Fig. 14*, i.e. for a period of time of *20 ms*. The major contribution of the surge arrester is to reduce the overvoltage stresses when of a discharge through the *CT* insulation.

IV.3 Final Observation

Both solutions previously presented refer to overvoltage elimination. In the case of existence of high frequency oscillations none of those would avoid the degradation of the insulation of the CT's. In this case, the solution would be to filter these oscillations. A suitable way to perform this filter action is to install a small capacitor to ground in the filter terminals.

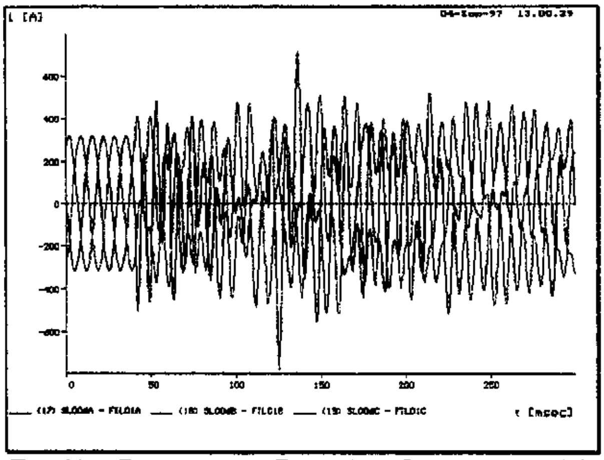

Fig. 13 – Current in the Entry- Bus Connection - of the Filter of SE-TBO

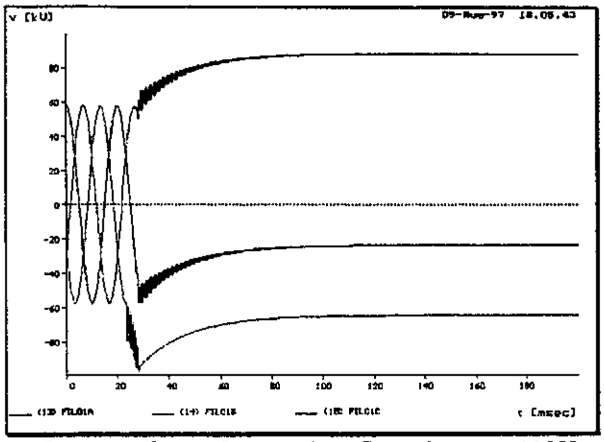

Fig. 14 – Overvoltages when Considering a 66 kV EXLIM Q Surge Arrester

V CONCLUSIONS

The degradation of the insulation of the CT's, it is probably associated to the stresses during the filter switch off. These stresses can be addressed to a long term – high amplitude discharging voltages, to the existence of high frequency oscillations or to both effects.

The overvoltages could result in discharges through the aged *CT's* insulation starting a phase to ground short circuit sustained by the capacitors charging and circulating through the stray capacitances of the equipment. This results in an increase of the voltage in the sound phases, as shown by *Fig 4*. The interruption of the fault current results in a further increase of the terminal voltage of the equipment that can cause the arcing restrike. This phenomenon may have been happening repeated times, determining the explosion of the *CT's*.

The grounding of the filters neutral solves the problem related to the stress of the CT's insulation due to overvoltages, avoiding the aging of them. Nevertheless, due to the existence of an earth return, when of phase to ground faults close to the SVAr Compensator, they are problems related to the current through the equipment – reactors, switches, capacitors, etc. These currents, resulting from the circulation of third harmonic components are larger than the rated current of the equipment, although presenting smaller duration.

It should be taken in consideration, that other type of switching, as of the transformers can also generate currents like these.

For supplying one path to ground the installation of surge arresters eliminate the *CT's* overvoltages, solving the problem of the degradation of their insulation. Once the filters still remain in the insulated wye configuration problems related to the circulation of fault currents through then does not exist.

Of the studied solutions, the most suitable is the installation of surge arresters, once it not modify the requests regarding the current stress of the equipment and the act in a way to keep the present protection sets.

The grounding of the neutral, would result in a probable change of the equipment, in order to withstand the currents that would circulate in cases of faults close the *SVAr Compensator*. It should also be necessary to re-evaluate the settings of the protection.

The possibility of the modification of the configuration of the filters should still be verified, once if possible, it could solve the overvoltage problems.

Finally, it is interesting to state that this paper stress the use of simulation tools in order to verify some equipment problems. This is a strong and new field and probably in a close future more and more applications like this will be developed. In cases like this not only the analyses itself can be carried out but also solutions can be discussed and the efficiency of a particular one close investigated.

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