Electric Power Systems Contingencies Analysis by Paraconsistent Logic Application

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Abstract-- In this paper we present Paraconsistent logic application at electric power system contingency analysis with risks identification. Para-consistent Logic is a non-classic logic whose foundations allow for the treatment of contradictions without invalidating the conclusions through algorithms named PANs - Para-consistent Analysis Nodes. In the equations of the PANs are calculated signals representing restrictions, risks and configurations of electric power systems networks. The "pre-Fault state" represented by the resulting evidence degree from PAN is evaluated together with the "post-Fault" information in a contingency evaluation. In that way the occurrence type and their parameters are classified by PANet with the purpose of offering an optimized re-establishment sequence to the power system. This method is being validated through off-line tests applied at the Eletropaulo Eletricidade de São Paulo, an electric power distribution utility company of São Paulo state, Brazil, which has a distribution network and a model substation of medium range.

Index Terms-- Distribution Power Systems, Network Distribution Reconfiguration, paraconsistent analysis networks, expert system.

I. INTRODUCTION

It is a well known fact that malfunctions in a power system are inevitable and there is a great number of reasons why these interruptions take place. They can be caused within or outside the power system, as a result of electrical and/or environmental phenomena, or even due to human error.

A permanent, speedy and reliable management of power distribution sub-systems and its components is paramount for the lowering of power distribution interruption index.

Utility companies in greater areas need new methods to offer more reliability in supplying power.

Due to the huge amount of vague, contradictory pieces of information that may be contained in the data received by control centers, a human operator can be led down a non-optimized or even wrong decision making path which could lead to great losses and delays in power systems.

Some works present an algorithm complexity and computing time which result in high costs that lead to the conclusion that non-classic logics are the best way forward for systems of analysis and treatment of uncertain data.

Using the theoretical concepts of Paraconsistent Logic, a non-classic logic, we present on this work an important part of an Expert System (ES) for decision making support for the power system reestablishment. Such ES is used for the analysis and treatment of possible contradictions in the information on risks and current configurations of the system received. In case a fault takes place it will be possible to inform users logged into the system as to how to proceed with actions for the reestablishment of sub-transmission of power systems in an orderly fashion thanks to aforementioned analysis.

II. THE ANNOTATED PARACONSISTENT LOGIC WITH ANNOTATION OF TWO VALUES APL2V

Annotated Paraconsistent Logic (APL) [4], a logic belonging to the class of Evidential Logic analyses the signals represented by notations allowing a description and formation of equation through algorithms. In APL [2] [4] [11] the propositional formulae are accompanied by notations. Each notation μ, belonging to a finite lattice τ, which attributes values to its correspondent propositional formula ρ. We can consider that each degree of evidence attributed to the proposition is a value contained in the values formed by the constants of notation of the reticulate.

APL2v [6] is an extension of APL [1] and each propositional sentence will be accompanied by a degree of favorable and unfavorable evidence which will give it a connotation of true, false, inconsistent or undetermined to the preposition[11]. APL2v can be represented by a lattice in which terminologies and conventions are established [6]. For instance we have the finite lattice of ‘four states’, figure 1 (a).
to be studied through a unitary square in the Cartesian plan, as in figure 1 (b).

Fig. 1. Finite Lattice and Unitary Square in the Cartesian Plan.

The first element of the pair named μ represents the degree in which favorable evidence sustain the proposition \( p \) and the second element \( \lambda \) represents the degree in which unfavorable evidences deny or reject proposition \( p \). From then on it is possible to perform the certainty degree calculus (\( D_c \)) and the contradiction calculus (\( D_{ct} \)) through the equations:

\[
D_c = \mu - \lambda \\
D_{ct} = (\mu + \lambda) - 1
\]

There are four extreme logic states and infinite non-extreme logic states within of the finite Lattice. In Paraconsistent analysis presented in [8] these non-extreme logic states will be of indicative importance for the decision making process.

III. SYSTEM OR PARACONSISTENT ANALISER NODE -PAN

In [8] a method for the treatment of uncertainties using Annotated Para-consistent Logic is presented. Two values are considered as outputs of the analysis:

A real certainty Degree \( D_{Cr} \) calculations for:

\[
D_{Cr} = 1 - \sqrt{(1 - |D_c|^2 + D_{ct}^2)}
\]

and:

\[
D_{Cr} = \sqrt{(1 - |D_c|^2 + D_{ct}^2) - 1}
\]

If: \( D_c > 0 \)

And an Interval of Certainty \( \varphi(±) \) for:

\[
\varphi = 1 - |D_{at}|
\]

Where: \( \varphi = \varphi(+) \) if \( D_{at} > 0 \)

\( \varphi = \varphi(-) \) if \( D_{at} < 0 \)

According to [8] an Algorithm that makes this type of analysis is named System or Paraconsistent Analysis Node. A Para-consistent Analysis Node - PAN is capable of receiving evidences and supplying a certainty value accompanied of its Interval of Certainty. Therefore, it is considered a Para-consistent Analysis Node - PAN the System of Analysis that receives Evidence Degrees in their inputs and supplies two values; one that represents the real Certainty Degree \( D_{Cr} \) and another, that is the signal of the Interval of Certainty \( \varphi(±) \).

IV. ALGORITHM OF THE PARACONSISTENT ANALYZER NODE

With the considerations presented here we can compute values using the obtained equations and build a System of Para-consistent analysis capable of offering a satisfactory answer derived from information collected from uncertain knowledge data base.

The PAN-Para-consistent Analysis Node is built by the "Algorithm of Paraconsistent Analysis of APL2v" as described bellow.

1. Enter with the input values
   \( \mu \) /* favorable evidence Degree \( 0 \leq \mu \leq 1 \)
   \( \lambda \) /* unfavorable evidence Degree \( 0 \leq \lambda \leq 1 \)

2. Calculate the Contradiction Degree
   \( D_{ct} = (\mu + \lambda) - 1 \)

3. Calculate the Interval of Certainty
   \( \varphi = 1 - |D_{at}| \)

4. Determine the output signal
   If \( \varphi \leq 0.25 \) Then do \( S1 = 0 \) and \( S2 = \varphi \)
   Indefinite and go to the item 10
   Or else go to the next step

5. Calculate the Certainty Degree
   \( D_c = \mu - \lambda \)

6. Calculate the distance \( D \)
   \( D = \sqrt{(1 - |D_c|^2) + D_{ct}^2} \)

7. Calculate the real Certainty Degree
   \( Se \) \( D_c > 0 \) \( D_{Cr} = (1 - D) \)
   \( Se \) \( D_c < 0 \) \( D_{Cr} = (D - 1) \)

8. Determine the signaling of the Interval of Certainty
   If \( \mu + \lambda > 1 \) Signal positive \( \varphi(+) = \varphi(+) \)
   If \( \mu + \lambda < 1 \) Signal negative \( \varphi(-) = \varphi(-) \)
   If \( \mu + \lambda = 1 \) Signal zero \( \varphi(0) = \varphi(0) \)

9. Present the outputs
   Do \( S1 = D_{Cr} \) and \( S2 = \varphi(±) \)

10. End

Two more lines are brought into the algorithm If there are connections among PANs forming networks of para-consistent analysis.

9. Calculate the real Evidence Degree
   \( \mu_{Er} = \frac{D_{Cr} + 1}{2} \)

10. Present the outputs
    Do \( S1 = \mu_{Er} \) and \( S2 = \varphi(±) \)

11. End

The symbolic representation of a PAN is presented in figure 2 where we have two inputs; favorable Evidence Degree \( \mu \) and unfavorable Evidence Degree \( \lambda \) of the regarding analyzed Proposition \( p \) and two output signals of results; the real
Certainty Degree $D_c$ and the Interval of Certainty symbolized by $\varphi_{(\pm)}$.

Fig. 2. Symbol of the PAN - Paraconsistent Analyser Node.

The application of Paraconsistent Logic through the methodology of APL2v presented in [8] considers propositions and works in an evidential fashion. Thus, creating propositions the Degrees of evidences that will feed the PANs is modeled by extracting information from measuring points, heuristics and data base.

V. ANALYSES OF CONTINGENCIES WITH RISKS IDENTIFICATION

The APL2v accepts extracted signals of evidences of contradictory information. With Paraconsistent Logic application is possible the inference of data for analysis of pre-fault states and his comparison with the post-fault state. In that way it is possible that, through the results of the analysis, an adaptation of the maneuvers is applied for the re-establishment of the electric power system. These maneuvers are directly conditioned to the topologic configuration of the substation and network. It is then considered that an Expert System should make control actions in three states of analysis to act in support for the re-establishment of electric power systems.

1. Pre-fault – Analyze of the System in operation.
2. Post-Fault – Analyze of the System in the contingency.
3. Re-establishment – Analyze of the System after contingency.

In a distribution system these three states are in a continuous loop of analysis and actions. The ideal is that the system always stayed in the state of pre-fault analysis. For each one of these states a Paraconsistent Analysis Network PANet composed of interlinked PANs makes the analysis generating evidences that will allow the re-establishment of the electric power system.

The PAN aiming at a great plan for re-establishment that should satisfy the following items:

1- to find a plan in a short interval of time (real time).
2- to minimize the number of maneuvers.
3- to recompose the System in the closer type of Operation possible of the state Pre-fault.
4- to reduce the number of interrupted consumers.
5- to assist the priority consumers.
6- to make arrangements so that no component is overloaded.
7- to maintain the radial structure of the System (without formation of rings).
8- Other objectives depending on the need of the company.

The figure 3 shows the actions of Expert Systems in an Electric System of Sub-transmission of Electric power.

VI. COMPOSITION OF THE PARACONSISTENT ANALYSIS NETWORK-PANET FOR IDENTIFICATION RISKS

In this work we will focus on the Paraconsistent analysis in the actions of the state of Pre-Fault. The Paraconsistent analysis in this state of Operation will originate the conditions to, along with other factors, form a sequential closing of breakers for the re-establishment of the System of Sub-transmission of Electric power in the post-fault state.

The APL2v methods applied to the pre-fault actions are:

1. Pre-Fault State – In that state the System is in operation regime. The System should be capable of analyzing and classifying the operation type. The type of Operation can be classified for instance, as one of the presented in [10]: a) Normal operation (parameters not violated and assisted load) b) Operation in urgency (violated parameters but assisted load) c) Operation in emergency (load off) d) Operation in restoration (process of load re-establishment).

The classification done by the Paraconsistent Analysis Network PANet will just generate an evidence signal whose value will define the operation type through a single proposition object (Po).

When the resulting Evidence Degree reaches the value 1 it means that the analyzed evidences acted by the partial propositions are confirming the object proposition. When the value of the resulting Evidence Degree decreasing and
approaches 0.5 (the Indefinite state), it means that the information brings forward evidence that weakens the affirmative to the proposition. In these conditions the analysis indicates that some parameters are violated in spite of the assisted load. An investigation in the PANs about the values of the evidence degrees of the partial propositions and their evidence intervals, allows an indication of the origin of the violation of the parameters and of the contradictions that are provoking that decrease of the resulting Evidence Degree from the object proposition.

When the resulting Evidence Degree crosses the value of the indefinite state 0.5 and approaches zero it means that the information that brings forward the evidences for the analysis about the partial propositions are indicating a larger refutation to the proposition object. Therefore, the evidences of risks, related to the restrictions and the current configuration of the system suggest that it is approaching an Emergency Operation State. investigation in PANs about the values of the evidence degrees of the partial propositions and their evidence intervals, brings information that qualify the formation of a better action in the sense of increasing the Degree of Evidence of the proposition object, to take it to the maximum value 1. Therefore, to take the Power System for the state of normal operation and without risks.

A. The Paraconsistent Analysis Network –PANet

According to the fundamental concepts of the Paraconsistent Logic an analysis should admit contradictions. This means that, when receives contradictory information the Paraconsistent System analyzes them and, without allowing the weight of the conflict to invalidate the analysis, he always produces an answer. It produces a value that expresses the reality. The linked PANs in the Paraconsistent Analysis Networks PANet are extracted algorithms of the APL2v and, unlike other types of treatment of uncertainty they do not admit factors, weight or changes in their structure that can compensate types of evidences of their inputs. For that reason the evidence Degrees presented for analysis should express the nature and the characteristics of the source of information. And because of that models are made and the variations within the discourse universe as well as the interrelation with other sources of information are considered.

B. modelings of the signals of evidence degrees of inputs for identification of risks

After the choice of a Proposition all of the possibly available evidences that will help to affirm that proposition will be found through knowledge extraction. The regarding Evidence Degrees will be modeled in the Discourse universe and with a variation that will depend on the nature of the source of information.

Other sources of information that will supply the Evidence Degrees for PANs to make partial proposition analysis are for instance; the signals originated from the System SCADA, that bring measurements of the tension, current e loads, rele states and protection, besides the profile of load of the system in the real time and topology of System.

The modeling and the extraction of information with the objective of generating the degrees of evidences to the risks are made in several ways as; using heuristics, it seeks in databases, interpretations of linguistic variables, statistical calculations, etc. An example of a generated evidence Degree of a load forecast in relation to certain schedule of the day is presented in the figure 5. The object Proposition is: Po “The Schedule is critical.”

\[ P = \text{The schedule is critical} \]

\[ P = \begin{cases} \text{True: if } & \mu = 1 \Rightarrow PA(1, 0) \\ \text{False: if } & \mu = 0 \Rightarrow PA(0, 1) \end{cases} \]

C. modelling of the risks

The risks can be classified and normalized from that classification. Then they are transformed into Evidences Degrees to be used in the analysis of the PANet.

A modeling regarding classification of risks is shown in the figure 6.

\[ P = \text{The state of breaker B}_k \]

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In this a classification of risks for analysis of contingency was made in the following way:

**Risks of the Switching** \( P_{sh} \) – They are related to the real configuration of the System of electric power Subtransmission. The configuration is related to the actual Switching of the distribution system configured by breakers states and Electric Switch in the real topology of the system. The proposition object of each bus and path circuits is related to the constraint on states of the breakers. Therefore, it is of the type: \( P_{sh} \) = The state of the breaker B_k is ON.

**Non-controllable risks** \( P_{NC} \) – They are the ones related to the nature: schedule of pick, incidence of rays, day of production, etc...
**Controllable risks** \( P_c \) – They are the ones related to the electric measurements as: current, tension, flow of loads, etc.

VII. **TOPOLOGY OF THE PARACONSISTENT ANALYSIS NETWORK PANET FOR RISK IDENTIFICATION**

The PANs are interlinked in PANet with their own modelling for each specified analysis of each area of the System of electric power Sub-transmission. Figure 7 shows the PANs interlinked for risk analysis used in this work.

![PANs interlinking for risk analysis](image)

Using the methodology and the equations of the APL2v, a high resulting evidence degree from the constraints of the partial proposition \( P \) result in a low evidence Degree of the proposition \( P_0 \). The value of the resulting Evidence Degree obtained in the output of PANet that analyzes the object Proposition: "The System is Normal" indicates what is the type of operation of the System and it will be Evidence for the analysis made by the network in the Post-Fault condition.

The topology of the network of Analysis used in this work is presented in figure 8.

![Interlinked PANs in a Paraconsistent Analysis Network](image)

We explained that other types of topologies can be used. Different topologies depend on the analysis characteristics and the nature of the sources of information used as generators of evidence degrees to feed the network.

In this project that treats of analysis of contingencies in the substation of Electric power feeds the PANet with information on the switching state and load in real time. At the same time in that it is generated the information the substation is monitored by the analyzer of risks. It is verified in that type of Operation the substation is. The screen of the Software used in the substation under test analysis is represented in the figure 9.

![Screen of the Software](image)

Are the states of the switches and of the breakers of the system, together with the measurements of the loads in real time of the substation that provide information about configuration. These information that, as it was seen, they enter in the classification of risks for switching, are analyzed in real time and stored temporarily. In the occurrence of the fault in the electric power System the analysis done by PANet change for Pos-fault state. In this case, the information that were stored will be used as evidences, together with the value of the Evidence Degree of the type of fault Operation that happened and will be capable by an paraconsistent analysis, to offer a suggestion of better sequence for the re-establishment. Is presented in the figure 10 the results of the analyses in a Circuit Breaker CB103 of the bus in study.

![Diagram and results of the analyses](image)

VIII. **CONCLUSION**

In this paper we present Contingency Analyzer that makes the analysis of risks based on Annotated Paraconsistent Logic. The study of the project is always made in the reasoning line used in Artificial Intelligence which allows us to show the several sources of information that compose a electric power system. The design of the analyzer of contingencies demanded
interpretative efforts in the extraction of the knowledge and in the methodology of application of the Paraconsistent Logic, which considers all of the sources as generators of signals in the form of Evidence Degrees. It is verified that these information, extracted and modeled are appropriate for treatment of signals using PANs - Paraconsistent Analysis Nodes. The PANs interlinked in network are capable of making an analysis through evidences of risks and configuration of switches of the System in real time. In that way the PANs generate information in the form of resulting Evidence Degree that, in the fault occurrence, will be used as information for the re-establishment of the System. The contingency analysis presented in this work should be considered as a small part of a great Paraconsistent expert system PES that, through APL, answers in a closer way to the human reasoning. The contingency analyzer is being studied in an off-line system applied to a small pilot System of Subtransmission of Electric power composed by 2 buses and a substation of small load. The contingency analyzer has presented good results and answers well to several situations when compared to the answers to previous situations, memorized in databases. The modulation parameters are of easy adjustment and the analyzer of contingencies is easily adapted to present resulting information suitable with reality. The next step is to adapt the resulting evidence Degrees of the contingency analysis to suggest re-establishments that select the several possibilities of maneuvers for transfers of loads. The criterion adopted regarding contingencies for the planning of expansion of the nets of transmission of Brazilian companies is N-1. The results obtained in the application of Paraconsistent expert system PES are directly referred the analysis of the operation and not to the planning of the expansion, being the term contingency used in the research in the sense of referring at levels of risks of lacks in the circuits of sub transmission in operation. Futures works in this research line with certainty will bring results more deepened.

IX. REFERENCES

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X. BIOGRAPHIES

João Inácio da Silva Filho was born in São Paulo, Brazil, on July 04, 1953. He received the PhD in Electric Engineering from the Polytechnic School of São Paulo University POLI/USP in the area of Digital Systems, and the master's degree in Microelectronic for the same Institution. J.J. Da Silva Filho is member of IEEE and the Coordinator of the Paraconsistent Applied Logic Group – GLPA of the Santa Cecilia University and member of the Group of Logic and Theory of the Science of IEA Institute of Advanced Studies of São Paulo University.

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