Load Balancing System to Low Voltage Grid using Petri Nets ⋆

Sicchar J. R * **Silva J. R** ** **Costa C. T., Jr.** ***

* *Control Automation Depart.,Technology High College,Amazonas State University,1200 Darcy Vargas Av, CEP 69050-020, Manaus,AM,Brazil (e-mail: jvilchez@ uea.edu.br).*
** *University of São Paulo, 2231 Prof. Melo Morais Av, CEP 5508-9000, Butantã,SP,Brazil (e-mail: reinaldor@usp.br)*
*** *ITEC, Electrical Engineering Department,Federal University of Pará, Belém,PA,Brazil, (e-mail: cartav@sufpa.br)*

Abstract: Current advances of smart grids are causing a demand for new operations and services, specially to the low voltage consumers grid. Among these processes,load balancing has a prominent capability for ensuring stable states between feeders. This paper presents some results about the design of an automated process to load balancing feeders in final consumption units of a small urban smart grid using a timed sliced Hierarchical Petri net. The main objective is to analyze the proposed system and establish an efficient and reliable workflow to automate load balancing and ensure stability while minimizes intervention. As a result it improves the quality of power service to the low voltage final consumers.

Keywords: Smart Grids,Load Balancing,Timed Hierarchical Petri Nets,Final Consumption Units.

1. INTRODUCTION

The perspective of having urban smart grids became closer since new approaches were developed relying in small urban smart grid (SUSG), Shahgoshtasbi (2014) or even to mix with the legacy system centered in hydro-power in what concerns low voltage (LV) units.

In this context, load balance feeders is an important issue to the quality of energy providing service, and several direct algorithms were proposed, Shahnia et al. (2014), Sharma et al. (2014), Sicchar et al. (2015) which should now be arranged in an automated process. These "hybrid algorithms" are in fact focused on distributed energy consumption management system (EMS). Thereby forming functional flow for automated processes within SG vision, Huang et al. (2015). Its extends energy consumption management until the final consumer units in LV circuits. Where among others services, are offered the voltage stability evaluation and the load balance for for residential feeders,Sicchar et al. (2015).

In a special way, it is observed that some consumer units loads, cause imbalance between feeders in LV grid. Then, identifying a problem that affects state equilibrium feeders grid, and energy quality supplied caused by power and electrical current cause imbalances among feeders,Sharma et al. (2014).Currently, some possibles alternatives like identification and minimization of losses are being developed as Automatic Feeders Reconfiguration (AFR). It is applied in LV grid and identifies some power losses, load imbalance and switches final consumers feeders between grid feeders,Siti et al. (2011), Shahnia et al. (2014).

However, previously alternatives mentioned show a wide gap in formal modeling for load balancing system design. This does not present a formal workflow validation for the AFR process,Alt et al. (2006), Wang (2015).For this reason, we indicated as an hypothesis: Petri nets (PN) can be used into balancing process performance in LV grid.That is, by formal modeling system is possible to obtain some process that improves load balancing efficiency. At where algorithms form a system and service that supporting the final consumers.

This system also have a supervision an information systems for maintaining the LV system (but are not addressed in this work). Which managed the demand of energy consumption. Petri nets, represent in this work the structure and system architecture and workflow tasks and control in system.

This article, explains in second section background related in Petri nets definitions and the scientific review in automatic feeders reconfiguration; in third section presents a proposal to the DPMS system model; in fourth section shows proposed algorithm design in PN; in the fifth section shows design analysis and validation based on the operational flow performance followed by its respective discussion; finally, last section presents the conclusion and and points to future work lines.

2. BACKGROUND

In this section, we put background in specific review related load balancing algorithms development in LV grid.

⋆ Author José R. Sicchar, thanks to FAPEAM and Amazon State University. Author Da Costa C.T.Jr.,thanks to Federal University of Pará.

Then, we have also review about PN use in SG. It will addressed, some specific definitions of PN that will be important for the development of this proposal.

2.1 Review Stage

As load balancing method within AFR context, we first can mention the transfers overload concentrated method (losses and loads) into specific feeder, working from three-phase final consumption units. This method, is based on minimizing current consumption achieved by *Fuzzy* machine inference and *Newton-Rhampsom's* optimization algorithm, between power consumption and power variation in each feeder,Siti et al. (2011).

Another method, focused only on single-phase final consumption units, minimizing power and voltage consumption use an hybrid genetic algorithm. In this case, also taking up load transfer but reconnecting single-phase consumers in same feeder in grid, with lower load level,Shahnia et al. (2014).

We can also mention, the hybrid load consumption algorithm model for final consumption units in LV grids,based on the Unified Modeling Language (UML)-PN paradigm, Sicchar et al. (2011). Which connects data acquisition, classification, programming and consumption forecast, and sending best selection for arrangement switching feeders in load balancing.

In currently article, We will continue load balancing in final consumption units feeders model but, based on hierarchical PN paradigm, using balancing diagnostic,current and load consumption prediction, minimization consumption and optimal arrangement sequence selection flow algorithms as hierarchical sub-processes in main PN.

Thereby, contributing with efficient process in load balancing, which can be used as an alternative method and/or interface in existent LV grid, or as support process in supervision center of a small urban smart grid (SUSG).

2.2 Definitions

- *Definition 2.2.1.Petri Net.*A Petri net structure is a directed weighted bipartite graph,according " (1)",Silva (2012):
$$N = (P, T, A, w). \quad (1)$$
where: "P" is the finite set of places,$P \neq \emptyset$. "T" is the finite set of transitions, T$\neq \emptyset$."A"⊆(PxT)∪(TxP) is the set of arcs from places to transitions and from transitions to places."w":A $\rightarrow$ {1,2,3,$\cdots$} is the weight function on the arcs. where: "P" is the finite set of places,$P \neq \emptyset$. "T" is the finite set of transitions, T$\neq \emptyset$."A"⊆(PxT)∪(TxP) is the set of arcs from places to transitions and from transitions to places."w":A $\rightarrow$ {1,2,3,$\cdots$} is the weight function on the arcs.
- *Definition 2.2.2. Timed Petri Net.*Defined by "(2)",Silva (2012):
$$N = (P, T, A, w, M0, f). \quad (2)$$
where: (*P, T, A,w,M0*) is a marked Petri net, Silva (2012),"f": T$\rightarrow$R$^+$ is a firing time function that assigns a positive real number to each transition on the net.
- *Definition 2.2.3. Hierarchical Petri net by Place Bounded Substitution.*In a PN structure give by "(3)",Silva (2012):
$$N = (P, T, F). \quad (3)$$
There is, an Y sub-net which limited by place so the replacement of this Y sub-net, generates another net N' = (P', T', F'), where: i) P'= $P \setminus T \cup \{S_y\}$, S_y is the new element that replaces Y; ii)T'=$T \setminus Y$;iii)F'=$F\setminus$Int(Y),Int(Y)is the inner Y arcs set, Silva (2012).

3. PROPOSAL

According, of hypothesis and the opportunity to improvement the load balancing process in the current structure of the LV distribution grid. We propose in this article: modeling an intelligent process for load feeder balancing in final consumption units using a Timed Hierarchical Petri Net (THPN), in order to obtain reliably and efficiently workflow, formally validated.

In fact, this process is based on algorithms of artificial intelligence as fuzzy logic and optimization systems; and also forecast algorithms based on stochastic process as Markov chains,Sicchar et al. (2015).

The contribution of the validated model, could be useful in reshaping modernization of the existing LV distribution grid structure (legacy system). It can be used as the implementation of a specific service in the process of automatic feeders reconfiguration in final consumption consumer units, within the scope of small urban smart grid.

Through hierarchical PN will be performed validation system design including its inner sub-processes,that make feeders reconfiguration system, called "**DPMS**". Which is explained in following sub-section.Similarly, use of Timed transitions in proposal model are intended to represent the most realistic way possible an entire period by simulation processing system, for consumer units feeders balancing.

In this particular case, takes a granular period of 60 minutes, i.e., seeking feeder reconfiguration lasting one hour, depending on sample consumption obtained at 10 minute intervals derived from real-time measurement, in the case of a SUSG. Thus, it is not covered in this case, the load balancing flow in existing secondary grid, which is the subject of future work.

In this article, will be developed according to initial proposal of the authors,Sicchar et al. (2011) however having a contribution a broad and integrated PN with hierarchical description of its sub-process. It will be based on the system developed to consumer units energy consumption diagnose,Sicchar et al. (2015) but now considering beyond imbalance diagnostic and consumption forecasting stage, more two stages: minimizing current consumption and switching sequence selection.

3.1 DPMS Architecture

The process system, is called "**DPMS**" because of its four stages or sub-processes:"Diagnose", "Prevision", "Minimization" and "Selection", each with a specific algorithm. So, these formed the DPMS system.

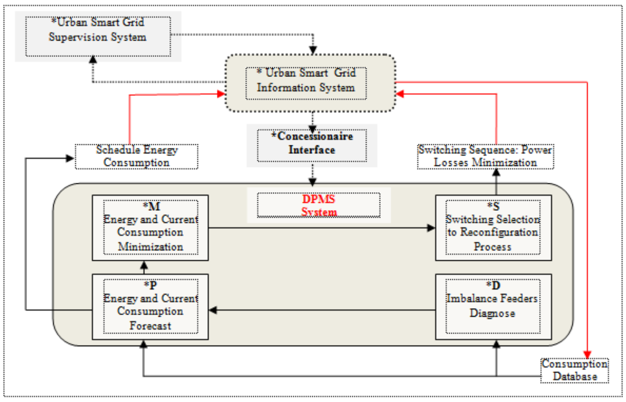

Fig. 1. DPMS Architecture

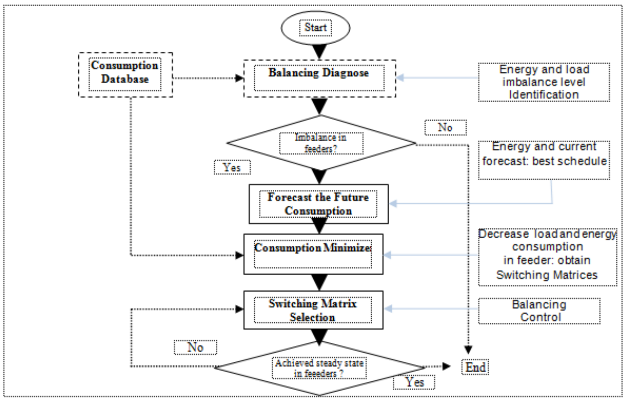

Fig. 2. DPMS Flowchart

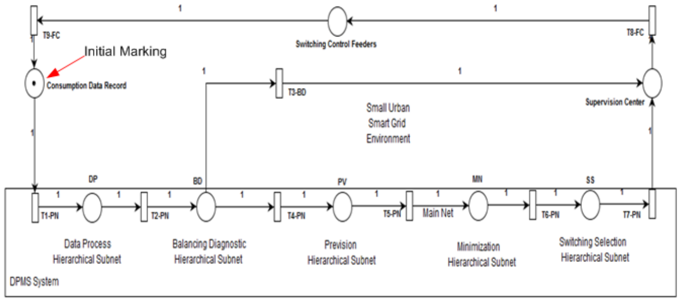

Fig. 3. DPMS THPN:Main Petri net

Thus, the DPMS system has an architecture formed as mentioned above, four specific processing (whose specific algorithms are not covered in this article):

- Balancing Diagnose or only "**D**" stage, that identifies the imbalance level in each feeder, Watching two situations: "balanced feeder", thus having the algorithm operating finish; and "unbalanced feeder" that activates the remaining stages of system, in sequence, starting with the consumption forecast step.
- Prevision Consumption or simply "**P**" stage, which only is activate when an imbalance is identified (in some feeder). It forecasts the current and energy consumption in feeders and returning this processing to the SG information system, that later develops the energy future consumption matrix indicating the trend of consumption to the final consumers.
- Minimization Consumption or just "**M**" stage, which procedure some combination of switching between feeders from the current and the future consumption of the energy and electrical current obtained by "P" stage, in order to minimize power losses effects and ensuring the equilibrium state in feeders.
- Switchin Sequence or only "**S**" stage. Which chooses the best switching combination from the "M" stage.
  This, selection is based on a correlation ratio analysis between the real value of consumption and with their values from the minimization stage.The final processing is sent to the information system SG as switching sequence, to procedure in fact the AFR.

In Fig. 1 we can see the DPMS architecture system model. It can be seen as a support process for system information to supervision center in SUSG environment.It can also be inserted, as an interface in the existing secondary grid system.

Then, we have the operation flow of the DPMS system. Which is shown in more details in Fig. 2. This flow, is started from consumption data processing, and after consumption diagnosis are identified possible losses and load imbalances.

In positive case, starts energy and current consumption prediction process, in each final consumer feeder. The main objective is to obtain,the future consumption matrix of electrical current.Furthermore, the prediction results serve to minimizing consumption process.

Followed by minimize consumption, looking for same sequences combinations of switching between feeders. Which are calculated from current and future values of electrical current consumption.

Finally, switching matrix selection chooses which through, send best combination for final consumer feeders balancing implementation. If imbalance minimizing process ends, otherwise proceeds in choosing other combinations for switching.

4. DPMS SYSTEM IN PETRI NETS

In Fig. 3 it is shown the "DPMS" system modeling in THPN. It describes the main PN of DPMS system. The hierarchical extension used is place bounded substitution (PBS) according to definition 2.2.3, being indicated with red arrow, the initial state "S0".

The inner workflow of DPMS system is formed as follows (see Fig.5):

- "**DP**".Data Process Hierarchical subnet.Which has all statistical treatmen sub-processes.It is formed by:"L_1-DP",that classifies power, current and energy consumption data."L_2-DP",which calculates average consumption."L_3-DP", that forms discrete consumption states.
- "**BD**".Balancing Diagnose Hierarchical subnet. Which has all consumption diagnose inference sub-processes. Which is represented by "L_4-BD", a PBS place that representing the inference machine design: load and energy consumption as input variables in inference system; load and energy consumption variation as

input variable; current consumption as output variable; the inference rules. And the output variable that obtain conditions to imbalance diagnose. In this work will not be covered in detail this sub-process. **BD** exit has two conditions: (final consumption unit) FCU balanced "T_9-BD"and, No balanced FCU "T_{10}-PN" that actives **PV** place.

- "**PV**".Prevision Hierarchical subnet, with electrical forecast current consumption sub-processes. It is formed by:"L_5-PV",which inserts discrete states consumption. "L_6-PV"that calculates incidences consumption. "L_7-PV", which obtain transition matrix. "L_8-PV",that obtain forecast electrical current consumption.
- "**MN**". Minimization Hierarchical subnet.It is formed by:"L_9-MN",which inserts measured electric current vector."L_{10}-MN",that inserts forecast current vector."L_{11}-MN", which forms minimization consumption vector."L_{12}-MN", that inserts minimization consumption formula."L_{13}-MN" which obtain arrangement switching matrices.
- "**SS**".Switching Selection Hierarchical subnet. Which has all switching selection inference sub-processes. Which is represented by "L_{18}-SS", a PBS place that representing the inference machine design. In this work is represented in detail the design of SS sub-process in section 5.3. After, this flow goes to supervision center (CS), and then feeder switching control (FC). The process goes through a measurement by data measurement (DM), whose flow is transferred as consumption data record (CDR).

5. RESULTS-VALIDATION ANALYSIS

In this section,we will show the validation results of DPMS system, modeled in THPN,using reachability graph, invariant analysis applied in Main DPSN THPN and also in Hierarchical DPMS THPN which shown all processes of system and also use siphon and traps analysis for validation workflow. For experimental results, was used as tool a free version of Pipe 4.3.0.

For simulation, timed transitions were used. It is distributed fixed time intervals, for each operation of sub-process,it was used T = 10 seconds,and for total integration operations add up to a full period of T = 60 seconds.

5.1 Main DPMS THPN validation

a) Reachability Graph. The Main DPMS Reachability graph is shown in Fig. 4. So, it represents the PN reachable diagram obtained from Its initial state "S0" highlighted in black, that also represents initial marking of PN.

   Through Main DPMS simulation, if verifies that does not exist deadlock.However, checking a possible conflict highlighted with a black arrow on "S2" **BD** place output, between transitions "T_3-BD" and "T_4-PN", due to balancing result that evaluates two conditions: balanced FCU or unbalanced FCU. However, this "conflict", will not be controlled due to consider a random order in system simulation when it executes balancing feeders analysis.

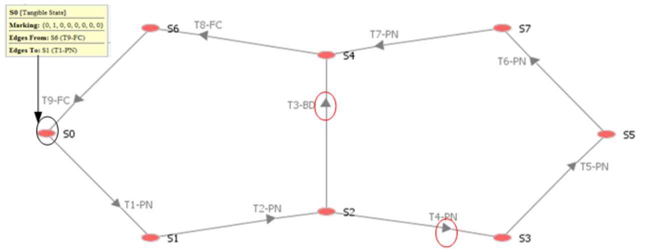

Fig. 4. Main DPMS Reachability Graph

b) Invariants Analysis. Still looking for reachability graph, we note that all processes of system are sequential.However, BD process is the most critical because to determine the end of process, if it is found that FCU feeders are balanced, or the continuation of process otherwise, activating PV process.This condition form, a specific place invariant: "PV" sub-process can not happen before "BD" sub-process.

   Through, with the invariants place (P-Invariants) it can be seen that the sequence of system sub-processes will only run one at a time, up until to develop the whole workflow system.

   Thus, we have the follow condition invariant: "BD", "PV","MN","SS" places cannot happen before "DP"sub-process. Thus, we have the follow condition:DP marking,BD marking,PV marking, MN marking and SS marking, should be less or equal to 1,"(4)":

$$M(DP) + M(BD) + M(PV)+ \\ M(MN) + M(SS) = 1 \tag{4}$$

   We have also the follow condition: "Supervision Center"(SC),"Feeder Switching Control"(FC), "Consumption Data Record" (CDR) places cannot happen before "BD"sub-process. If any as a result of the process, FCU balanced:

$$M(BD) + M(SC) + M(FC) + M(CDR) \leq 1 \tag{5}$$

   By P-Invariants result, we can verified that invariants indicates aboven, are true:

$$M(BD) + M(CDR) + M(DP)+ \\ M(FC) + M(MN) + M(PV)+ \\ M(SS) + M(SC) = 1 \tag{6}$$

   The transition invariants (T-invariants) can be used to verify the order of each subprocess system. Showing the sequence of the flow system is well structured. Through, the PN Invariants is shown in $2x9$ constant"T-Invariants" matrix depending on "T_{1-PN}","T_{2-PN}","T_{3-BD}","T_{4-PN}","T_{5-PN}", "T_{6-PN}","T_{7-PN}","T_{8-FC}","T_{9-FC}" transitions:

$$T_{Inv} = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 & 1 \\ 1 & 1 & 0 & \cdots & 1 & 1 \end{bmatrix} \begin{bmatrix} T_{1-PN} \\ T_{2-PN} \\ T_{3-BD} \\ T_{4-PN} \\ T_{5-PN} \\ \vdots \\ T_{9-FC} \end{bmatrix} \tag{7}$$

   We can see, also that the net is covered by positive T-Invariants, therefore it might be textbfbounded and **live**.

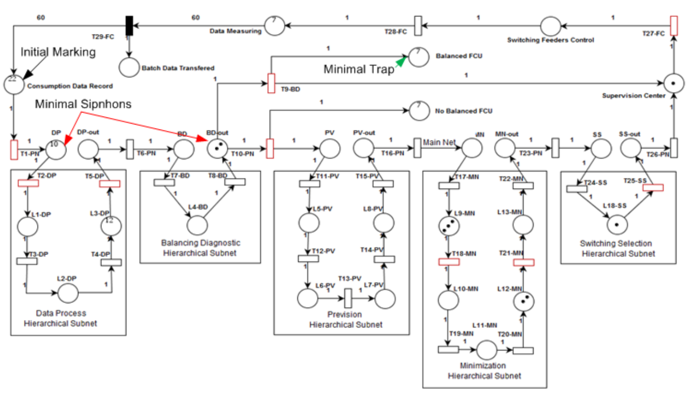

Fig. 5. DPMS THPN Simulation

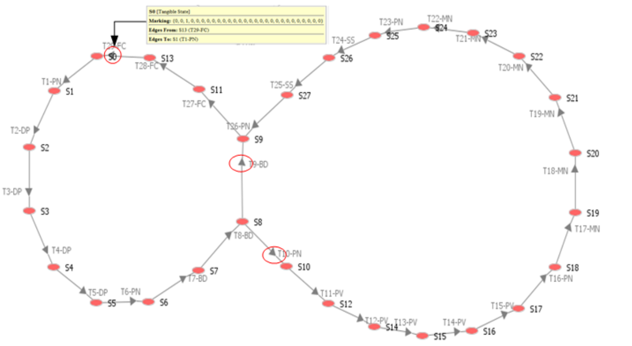

Fig. 6. DPMS THPN Reachability Graph with initial marking and conflicts

5.2 Hierarchical DPMS THPN validation

In Figure 5 it is shown the Hierarchical DPMS THPN simulation.Were performed 1500 "firings" with a period of 60 seconds between each, in order to have a complete operating in 1 minute. So, Were considered 60 FCU in SUSG, to be targets of balancing feeders analysis process. Thus, in "**CDR**" place there are electrical current and energy consumption of this 60 FCU.During DPMS system simulation is verifying efficiently workflow, and there is not deadlock or conflicts (marked in red in Figure 6) like main PN, that needs regulatory control.

However, it is found some "**siphons focus**" especially on "**DP**" and "**BDout**"(in red arrows), where are accumulated and consumed several tokens continuously, but it normalizes and adjusts over time.

It is, also found some "traps focus" in "**Balanced FCU**"(in green arrow) where which are accumulated several tokens, but this is actually equal to "**No balanced FCU**": both are only process counters, to facilitate processing system count.

The DPMS THPN Reachability graph is shown in Figure 6. It represents the diagram of reachable states of the PN. Its initial state S_0 highlighted in red. If verifies that does not exist deadlock, and that the PN it might be textbfbounded and **live**.

Looking for reachability graph, we note that all some specifics place invariant: "PV" sub-process can not happen before "BD" sub-process.But also, we have the follow

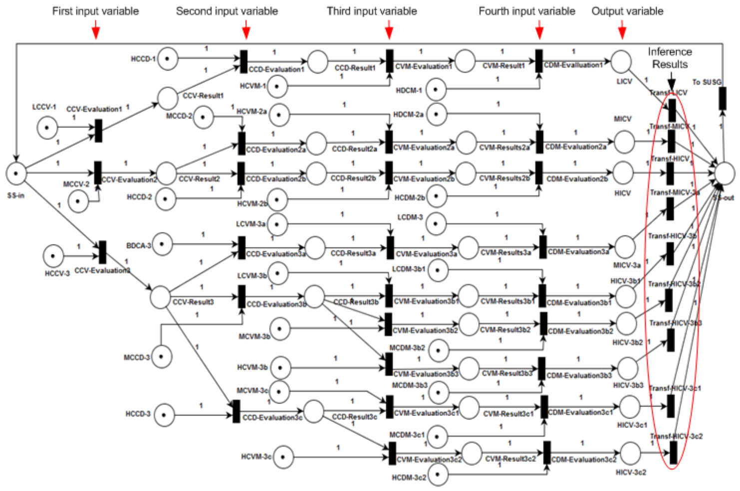

Fig. 7. Switching Selection sub-net

condition invariant: "BD", "PV","MN","SS", "SC","FC", "Data Measuring (DM)", and "CDR", places cannot happen before "DP"sub-process. Thus, we have the follow condition shown in "8":

$$\begin{aligned} &M(DP) + M(BD) + M(PV) + \\ &M(MN) + M(SS) + M(SC) + \\ &M(FC) + M(DM) + M(CDR) = 1 \end{aligned} \tag{8}$$

By P-Invariants result, we can verified that invariants indicates aboven, are true:

$$\begin{aligned} &M(BD) + M(BD-out) + M(CDR) + M(DM) + \\ &M(DP) + M(DP-out) + M(L10-PV) + \\ &M(L11-MN) + M(L12-MN) + M(L13-MN) + \\ &M(L14-MN) + M(L15-MN) + M(L16-SS) + \\ &M(L1-DP) + M(L2-DP) + M(L3-DP) + \\ &M(L6-BD) + M(L7-PV) + M(L8-PV) \\ &M(L9-PV) + M(MN) + M(MN-out) + M(PV) + \\ &M(PV-out) + M(SS) + M(SS-out) + \\ &M(SC) + M(FC) = 1 \end{aligned} \tag{9}$$

5.3 Switching Selection sub-net validation

For the Switching Selection sub-process was modeled an hierarchical sub-net, as illustrated in Figure 7. It represents the model of inference selection of minimized consumption values of electric current performed by MN sub-process.

This is formed by four input variables: Current Consumption Value (CCV), Current Consumption Variation (CCD), Current Value Minimized (CVM), Current Variation Minimized (CDM)and a output variable, Current Correlation Value (ICV). All variables with three performance levels: low (L), medium (M) and high (H). With results highlighted in red, are selected the optimal switching matrix. Which can by means of this sub-net is implemented "Mamdani Fuzzy inference" model for selection of output combinations having the highest current correlation value.

In the case of the first inference rule is composed of the following stream: the first input variable "CCV" is evaluated (CCV-Evaluation1 transition), presenting as LCCV-1 result. The second input variable "CCD" is evaluated (CCD-Evaluation1 transition) presenting as HCVM-1 result. The third input variable "CVM" is evaluated

(CVM-Evaluation1 transition) and presented as HDCM-1 result. The fourth variable enters "CDM" is evaluated (CDM-Evaluation1 transition) presenting the final result of the output variable "ICV" LICV. Then transferred (transferrin-LCCV) to the output of the subnet to forward this information to the monitoring center of SUSG.

This sub-process represents "nine possible solutions" to the current variation correlation (inference rules) showed in Table 1. Which can assume low, medium and high correlation of current variation.

Table 1. Inference rules of Switching Selection sub-net

If	and	and	and	then
LCCV	HCCD	HCVM	HCDM	LICV
MCCV	MCCD	HCVM	HCDM	MICV
MCCV	HCCD	HCVM	HCDM	HICV
HCCV	LCCD	LCVM	LCDM	MICV
HCCV	MCCD	MCVM	MCDM	HICV
HCCV	MCCD	HCVM	MCDM	HICV
HCCV	MCCD	LCVM	LCDM	HICV
HCCV	HCCD	MCVM	MCDM	HICV
HCCV	HCCD	HCVM	HCDM	HICV

In this case by means of transition invariants it is possible to confirm the formation of each inference rules. Checking that they are well formed with all conditional and actions.

Rule 1 Training:

$$\begin{array}{c} CCD - Ev2b + CCV - Ev2 + CDM - Ev2b \\ CVM - Ev3a + TransfHICV + ToSUSG \end{array} \tag{10}$$

Rule 2 Training:

$$\begin{array}{c} CCD - Ev3b + CCV - Ev3 + CDM - Ev3b1 \\ CVM - Ev3b1 + TransfHICV3b + ToSUSG \end{array} \tag{11}$$

Rule 3 Training:

$$\begin{array}{c} CCD - Ev3b + CCV - Ev3 + CDM - Ev3b2 \\ CVM - Ev3b2 + TransfHICV3b2 + ToSUSG \end{array} \tag{12}$$

For the other rules can also be applied the same procedure.

6. CONCLUSION

A model Petri net, of load balancing process, called DPMS system to final consumption units in low voltage secondary grid, has been presented from which it is shown workflow formal validation. Having been used a timed hierarchical Petri net, to represent a dynamic abstraction of the operation flow of main and internal processes that form the DPMS system.Through the net synthesis,the reachability graph,invariant analysis and, workflow simulation, among others the vividness and limited network properties were checked.Verifying in summary efficiently operation of system without deadlocks and conflicts, that requested implementation of any regulatory control.

It was also presented in detail the inference procedure for switching selection sub-process. Noting that from the transition invariants is possible to verify the formation of the inference system rules.

Suggested future steps develop model DPMS system using timed hierarchical colored Petri nets,to further improve computational efficiency.

ACKNOWLEDGEMENTS

The authors thank UEPA, UFPA, USP and FAPEAM, for allowing scientific achievement of this proposal.

REFERENCES

Alt, M., Gorlatch, S., Hoheisel, A., and Pohl, H.W. (2006). Using high level petri nets for hierarchical grid workflows. In A. Round (ed.), *Advances in Enzymology*, volume 2, 1–87. Academic Press, New York, 3rd edition.

Huang, Y., Mao, S., and Nelms, R. (2015). Smooth scheduling for electricity distribution in the smart grid. volume 9, 966–977. IEEE System Journal, New York, 3rd edition.

Shahgoshtasbi, D. (2014). A new intelligent neuro–fuzzy paradigm for energy-efficient homes. In A. Round (ed.), *Advances in Enzymology*, volume 8, 664–673. Systems Journal, IEEE Transactions, New York, 3rd edition.

Shahnia, F., Wolfs, P., and Ghosh, A. (2014). Voltage unbalance improvement in low voltage residential with rooftop pvs using custom power devices. In E. Power and E. Systems (eds.), *Advances in Enzymology*, volume 55, 362–377. Elsevier, New York, 3rd edition.

Sharma, I., Cañizares, C., and Bhattacharya, K. (2014). Smart charging of pevs penetrating into residential distribution systems. In A. Round (ed.), *Advances in Enzymology*, volume 5, 1196–1209. IEEE Transactions on Smart Grid, New York, 3rd edition.

Sicchar, J., Jr., C.D.C., Salmon, A., Silva, J., Pina, I., and Gomes, R. (2011). Sistema inteligente para análise de consumo de energia elétrica em smart grid de baixa tensão. In P. in X SBAI 2011 (ed.), *Advances in Enzymology*, volume 1, 1–6. SBAI 2011, New York, 3rd edition.

Sicchar, J., Jr., C.D.C., Silva, J., and Freitas, R.D. (2015). Gerenciamento de consumo de energia em residências com frame gcr. In P. in XII SBAI 2015 (ed.), *Advances in Enzymology*, volume 1, 1–6. SBAI 2015, New York, 3rd edition.

Silva, J. (2012). Timed petri nets. chapter 16. petri nets manufacturing and computing science. In INTECH (ed.), *Advances in Enzymology*, volume 1, 359–378. Intech, New York, 3rd edition.

Siti, W., Jimoh, A., and Nicolae, D. (2011). Distribution network phase load balancing as a combinatorial optimization problem using fuzzy logic and newton-raphson. In E. Electric Power Systems (ed.), *Advances in Enzymology*, volume 22, 1079–1087. Elsevier, New York, 3rd edition.

Wang, L. (2015). Knowledge representation and general petri net models for power grid fault diagnosis. In I.J.. Magazines (ed.), *Advances in Enzymology*, volume 9, 866–1087. IET, New York, 3rd edition.