Efficient computational techniques for power systems reliability assessment

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1. Introduction

Modeling and performance assessment of power systems play an important role in an *optimal design* and *efficient operation* of such systems. The main criterion considered for the assessment of the performances of these systems is the *energy delivery and supply safety* according to the contract relations set up between suppliers and consumers. The high level of technological integration, the interconnections between systems and the diversity of the customers allowed the creation of a real *energy market,* i.e. a free contract relationship between suppliers and customers which is possible only if the *services bought are guaranteed*. Further to the occurrence of the energy market, it occurred the competition between suppliers and therefore increased requirements related to the supply safety and, obviously, the taking over of the financial liabilities in case it is not fulfilled.

The modeling of the reliability of the power systems is already a classical issue (Billinton 83) as the reliability analysis is a compulsory request, and the modeling techniques are characterized by advanced performances. The actual concerns are mostly related to the *efficient algorithms* field, respectively to the time consuming and the accuracy of the methods used. Nevertheless, the larger and larger dimensions of systems, the non–homogenous electricity equipment, and a higher exigency of the clients are representing new requirements to be met by the analysis–makers and the demand to perform accurate modeling is growing.

The new requirements of the reliability evaluation approach generated by the complexity of the installations and their behavior features impose:

- a more accurate modeling of the intervention of the control, protection and instrumentation systems or, more general, of the integrated computerized systems which perform these functions;
- the taking into account based on the events occurred of the transient change of the analyzed systems structure;
- the need to consider some important deterministic influences related to the operation planning and repairs policy;

As far as the reliability analyses are concerned, the power systems are characterized by the followings:

- there are included in the category of large and very large systems;
- as for the behavior in time is concerned, they consists of non–homogenous components and of multiple damaging mechanisms leading to the need to consider several damaging ways and multiple states;
- they are equipped with protection systems which generate an advanced functional dependence between components and related to the evolution in time;
- the use of several corrective and predictive maintenance policies as the components are basically non – monitored by operators, but electronically tested or monitored;
- concerning failures or failure features, there are systems provided with failures rapid propagation or components simultaneous failure, as well as common failures.

In this paper, a new modeling technique for power systems reliability assessment is presented. The main contribution lies in the *dependability* modeling of the power system's structure with *Petri Nets* (PN) (Jensen 1991)

Reliability Modeling through PN

The Petri Net, which is presented in Figure 2, corresponds to a testing network example (*see Figure 1*). This PN is structured in two parts. The first part contained several Petri sub-nets, each of them formed by two places, two stochastic transitions and four regular arcs. There is a Petri sub-net for every component of system, as it is indicated in the diagram line. This first part of the Petri net is used to simulate the behaviour of all components through possible states.

The second part is used to determine whether the system load-points are in an up state or in a down state. This thing is made by simulating the flow of electrical energy from one node to other through the lines. For this, there is a place for every component. The transition from a place to other (from source to destination) is made through an immediate transition corresponding to an existing line. This transition has four arcs, in correspondence with the following four conditions:

- the line is functional – the place corresponding to repair state of line is empty
- in the source place is a token
- destination place is empty (if it's not this node is already supplied)
- a change happened before (a line was repaired or failed)

For the first and third condition there are used inhibitor arc. For the second condition there is used a regular arc. For the fourth condition two places and an inhibitor arc are needed. These places are named CHANGE and MODE. The meaning of these two places is the following: after a change happened the CHANGE place receives one token. The next move is that CHANGE and MODE places become both empty.

From this point the function of Petri net is the following:

- all the places from the second part of Petri net get empty (all places from this part of net reset);
- in source node (NODE 1) is generated a token, using an immediate transition which is conditioned by MODE place;
- the second part of Petri net begin to simulate the electrical energy flow; this sequence is finished when all reachable nodes (from electrical point of view) get a token.

After all these operations, all immediate transitions are disable and the stochastic transitions are enable again and the network waits until something happens (failure or repair).

During the time when stochastic transitions are enabled, the presence of a token in a place corresponding to a node of electrical network means that node is supplied with electrical energy.

For the following three case studies, in table 2 are presented the computed system reliability indices:

- *case study 1*: the system is in a success state if both consumers (LP4 and LP5) are supplied;
- *case study 2*: the system is in a success state if first consumer (LP4) is supplied;
- *case study 3*: the system is in a success state if second consumer (LP5) is supplied.

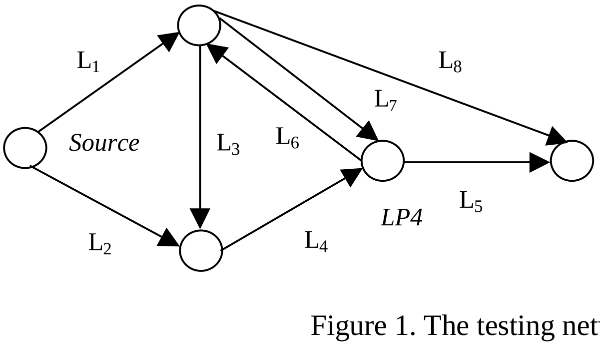

Figure 1. The testing network (Bailey 1986)

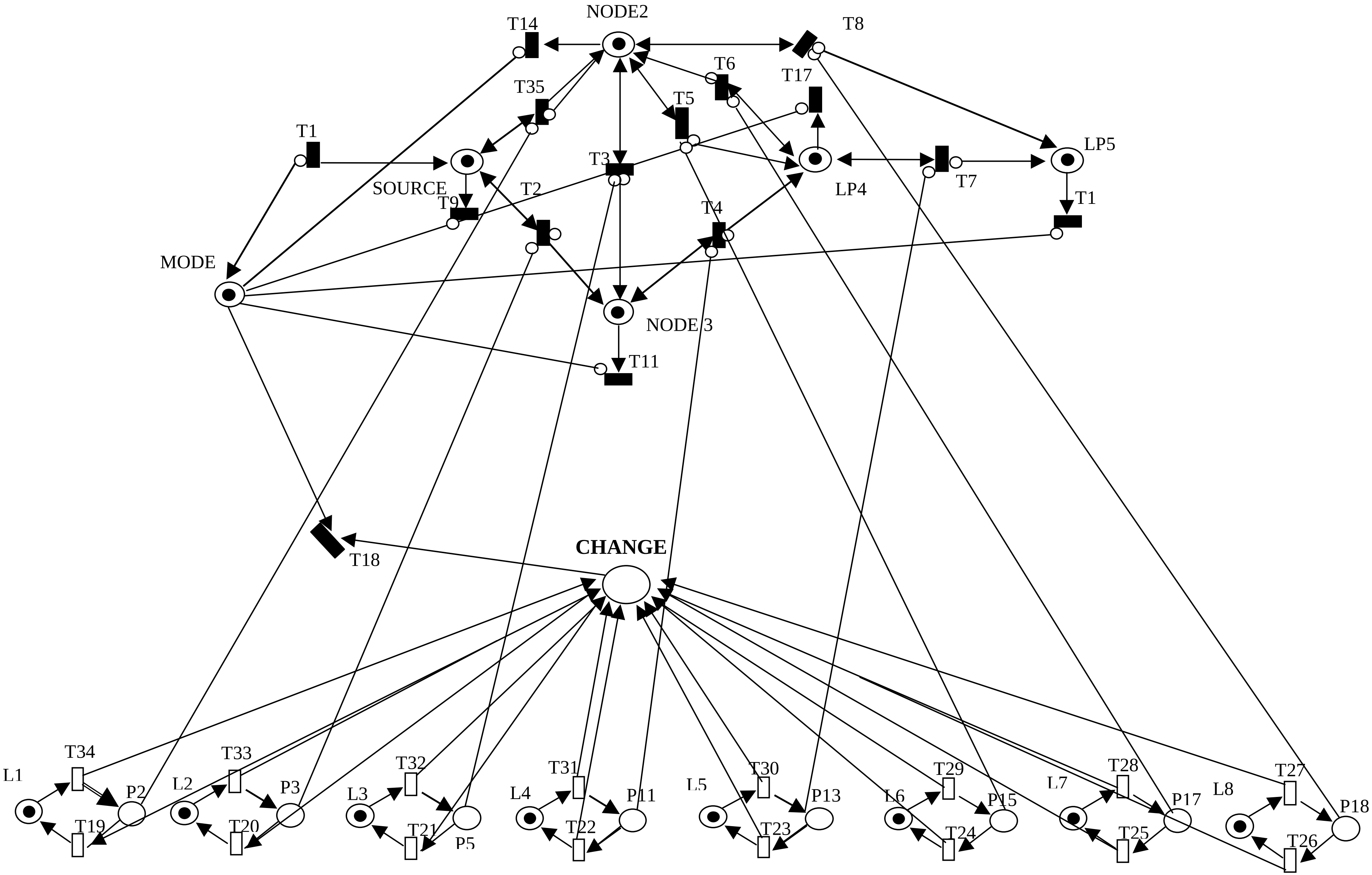

Figure 2. The Petri Net Model for the proposed network (depicted in Figure 1)

Table 1: Proposed component reliability data which are used for testing and validation (A) (Bailey 1986), and a real case (B), for the above-mentioned case studies

Index	Line *(k=1..8)*	
	A	B
Failure rate λ_k [h^{-1}]	0.1	*0.0003*
Repair rate μ_k [h^{-1}]	0.1	*0.04*

Table2. System indices for three case studies

Indices	*Case study 1 (A/B)*	*Case study 2 (A/B)*	*Case study 3 (A/B)*
Success probability	0.335937 / *0.999778*	0.46875 / *0.999834*	0.414062 / *0.99833*
Failure probability	0.664063 / *0.000222*	0.53125 / *0.000166*	0.585938/ *0.00167*
Load-point annual availability [hr]	2942.81 / *8758.06*	4106.25 / *8758.55*	3627.19 / *8758.54*
Load-point annual unavailability [hr]	5817.19 / *1.94*	4653.75 / *1.45*	5132.81 / *1.46*
Expected Number of Load Curtailments [occ/yr]	718.59 / *0.155307*	684.375 / *0.11606*	718.59 / *0.116914*
Average Duration of Load Curtailment [hr/occ]	8.09 / *12.49*	6.8 / *12.49*	7.14 / *12.49*

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