Hybrid Socio-Technical & Economic Interaction Networks Application: the Theoretical Cost of Penalties for Non-Delivery of Power Energy

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Abstract **– The protection of critical infrastructures is essential to the future sustainability of electric power systems. The resilience at the smart meters type threats requires an integrated interdisciplinary approach of the technical and the social components of smart substation. The manner in which the decisions regarding the designing of the electrical substations for the evacuation of the electrical energy produced in a power plant is analyzed and proposed the cost of penalties calculation methodology for nondelivery of power energy from the point of view of socio-technical services.**

Keywords **– Cost of penalties, Decision, Electrical substation, Scheme, Socio-tehnical system.**

1. Introduction

An electrical substation represents a node within a grid to which are connected several elements: generators, electrical lines, power transformers etc. In [1] there are highlighted the performance criteria for substations of the XXI century: reliability, security, interoperatibility, low impact on the environment, flexibility, reconfigurability, controllability, maintenance, reduced operating costs, addressing of the increasing expectations of customers regarding an affordable and reliable electric service.

The implementation of new technologies within power systems is changing the image that we have on the configuration of the electrical grid and the elements that can be integrated into it [2]. It is necessary to asses the new functionalities that are included into the next generation digital substations, so as to guarantee cost-effective, high functionality and future proofed automation of the end-to-end grid [3].

When increasing the number of intelligent electronic devices in a substation, the overall substation´s reliability is reduced. Each new added element has a direct impact on the mean operation time between failures of the substation. Therefore, the vital redundancy level has to be considered in the network reconfiguration.

The world in which we live is a complex, large-scale, interconnected, open and sociotechnical world [4]. From the point of view of the sociotechnical systems, an electrical substation is a dynamic system, which involves both social and technical aspects, being characterized by inputs and outputs from at to other processes. The identification of evaluation criteria for the social aspects of the technical system [5, 6] proved to be a difficult task. STIN models approach such sociotechnical interaction network [7]. The most important parts of the electrical substations considered for the evacuation of the electrical energy produced in a power plant are:

- *cybersecurity*: protecting the electricity grid and several points of access in the system from cyber attacks who compromise the critical information;

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- *resilience with DERs* (resistance at disturbances): diversity, redundance of the information, modularity, autonomy;
- *reliability in functioning*: it functions even in the case of disability of some of the components, it can be physically, communicationally and socially analyzed;
- *distributed vs centralized control*: territorial dispatcher centre and national energy dispatcher centre;
- *autonomy and mastering*: detectors, decisions, operators, control.
- *ability to accommodate system changes.*

A series of basic information is known, such as: the profile and emplacement of the substation, the level of pollution, meteorological information, data concerning the planning of investition, elaborating the projects, etc. It is required to cover a series of decisions regarding the choice of a solution for the substations' diagrams of connections. Figure 1 illustrates the main steps in the rational decision making model in socio-technical systems and the links between them.

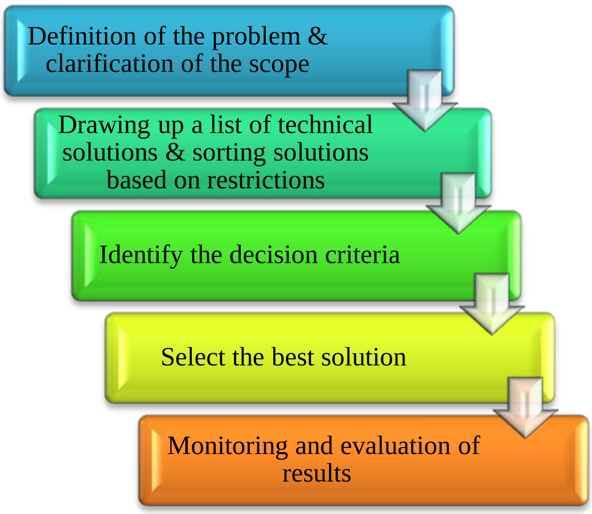


Figure1. Main steps in the rational decision making model in socio-technical systems.

The paper is organized as follows. Section 2 defines the problem, clarifies the purpose and identifies the main technical, economical and social aspects for assessing the substation scheme. Section 3 presents the possible solutions and restrictions for the switching scheme of connections for the high voltage substations from a technical point of view and agrees the criteria of decision. Section 4 is devoted to a calculation algorithm for theoretical cost of penalties for non-delivery of power energy, from the point of view of socio-technical services. In section 5, we applied the proposed algorithm for a hypothetical but still semi-realistic study case (400/110 kV substation). Section 6 reports the conclusions and possible future research.

2. Problem definition & clarification of the scope

We intend to analyse the manner in which the decisions regarding the designing of the electrical substations were connected to one power plant with n_G generator groups, each are with apparent power S_{nG} taken, from the point of view of socio-technical services of power supply.

The electrical energy produced in power plants of different types (e.g. coal power plants, gas power plants, hydro power plants, wind power plants, solar arrays), each consisting of one or more electricity generation units, will be evacuated via two electrical substations, with the voltage U_1, respectively U_2 (Figure 2): at consumers with the apparent power S_{C1}, S_{C2} and in the power system (S_{S1}, S_{S2}). A scheme includes transformers/ autotransformers to change voltage levels between voltages U_1 and voltages U_2.

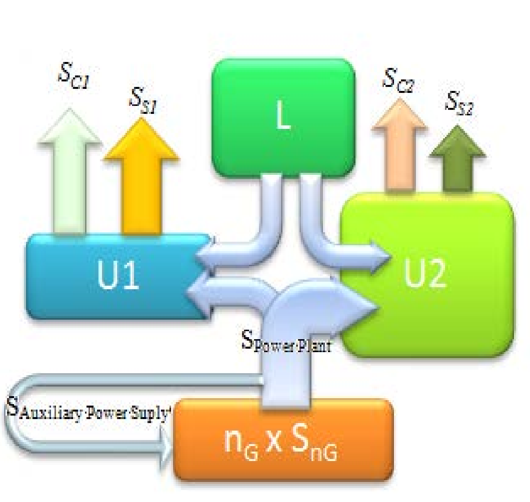


Figure 2. Block diagram (technical perspective) for the evacuation of the electrical energy produced in a power plant with n_G generators.

We will take into consideration:

- **Technical standpoint:** nominal voltage, the offer of major equipment and devices producers [1, 2] technological power and energy losses in transformers or autotransformers [8], new maintenance strategies [9], operation procedures [10, 11], hybrid emergency power system [12], real-time monitoring, control and analytics within dynamic smart grid [3], data acquisition method, SCADA and packet telecoms domains [4, 13], key automation technologies and architectures in the substation automation [11, 14] etc.

- **Economical standpoint:** investment costs for the electrical installations, the costs of power and energy losses in transformers and auto-transformers, penalties for nondelivering the electrical energy and compensation for failure to accept contracted energy, maintenance costs [9, 12, 15], facilitate future expansion, understand where budgets are being focused and resource is being allocated to drive the practical implementation of the smart grid [14, 16, 17].

- **Standpoints concerning the regulatory and social consequences of a potential non-delivery of power energy:** market models for smart utilities [4] and the digital transformation [13]**,** the impact on the quality of electrical energy [15], damage on the environment [18], injuries or loss of life [19, 20], any constraints imposed of site characteristics [21], consumers [22], producers, prosumers and the implications of new European regulation [23] and the strategic plans and priorities of electric utilities for cascade effects that can affect the electrical grid [24], etc.

3. Selection of Switching Scheme

3.1 The possible solutions and restrictions. Technical point of view

The single-line diagram for electrical substations are independent, so the decision of the optimal schema is taken separately for each of the substations with the voltages U_1 and U_2 (expressed in kV).

For the beginning, we mention the type and the number of circuits from an electrical substation: generator circuits/ generator-transformer block circuits, circuits of link transformers, consumer line circuit (overhead line or underground cables), system line circuits.

Determining the number of the line circuits that are connected in a substation is made by long-term loading of these electrical lines: the maximum electric load for longer time duration (S_M), the number of charged zones and the allowable load on a single circuit, depending on the cross section of the wires.

The usual schema of connections for substations that can be taken into account for preparing the solution lists are: single busbar collector (1BC), single sectionalized busbar collector (1BCS), double bus and one breaker (2BC), main busbar collector and transfer busbar (1BC+B_T), double busbar collector and transfer busbar (2 BC+B_T), ring busbar (preferable 4-6 sides), type H schema, etc. [9].

The types of schema of connections are specific to the voltage level that they are chosen for.

The following considerations could be highlighted:

- Ring busbar (polygonal) schemes are specific only for 220-750kV substations, which have a reduced number of circuits due to the field-location and the difficulties of building the systems of protection by relays;

- At high voltage, the simple solution (1BC) is taken into consideration if: the number of circuits is small, the power transit is reduced, the equipment is very reliable; the consumers are not very sensitive to disruptions or there is another line to supply it;

- At medium voltage or for indoor substations with $U \leq 110$kV, we do not choose solutions with transfer busbar (because the space is limited by the disposition in the building).

In case there are suggested solutions of schemes of connections that differ from 1 BC, we keep in mind those new circuits which are present in the scheme: the transversal coupler, the longitudinal coupler, the bypass coupler, the coupler with multiple functions etc. (the type and number of the coupler circuits depend on the type of the suggested scheme).

3.2. The decision criteria for selecting the best solutions. Techico-economical point of view

In order to rank the possible solutions, we suggest the minimisation of the present total discount cost criteria.

The overall calculation formula for the present total discount cost (PDTC) is:

$$PTDC = CI + \left(C_{OMMyear} + C_{\Delta PETyear} + + CP_{year}\right) \cdot T_{st} \quad (1)$$

where: CI is the investment cost, $C_{OMMyear}$ is the annual operation, monitoring and maintenance cost; $C_{\Delta PETyear}$ is annual cost of power and energy losses in the link tranformers or autotransformers between the substations with the voltages U_1 and U_2; CP_{year} represents the annual cost of the penalties for non-delivery of power energy to the consumer areas; T_{st} is the value for discounted costs calculation.

The investment costs. The investment costs are equal to the sum of the costs of all the cells that make up a substation and they can be determined according to the producers' offer. (Table 1).

The investment cost (CI) is the purchase price added to the installation cost, expressed in euros [€].

The costs of operation, monitoring and maintenance. The annual operation, monitoring and maintenance cost (COMMyear), expressed in [€/year], can be determined with:

$$C_{OMM} = p \cdot CI \quad (2)$$

where p is the coefficient for OMM cost, function of the voltage level [%/year].

For example, the operating data collected for 110kV substations indicates a ratio of about 3.3% between investment costs and operating, monitoring and maintenance costs. This percentage decreases as the voltage of substation increases.

Table 1. Switching scheme cost comparation [17], if power transformer cost are not included.

Switching Scheme	Approx. Cost Comparation
Single Busbar Collector	100%
Ring Bus (Polygon)	114%
Single Sectionalized Busbar	122%
Main and Transfer Busbar	143%
Breaker and a Half	156%
Double Breaker, Double Bus	214%

The cost of power losses and energy losses in transformers. The annual cost of power and energy losses in transformers, expressed in [€/year], can be determined with [8]:

$$C_{\Delta PETyear} = P_0 \cdot \left(\frac{c_p}{T_{NOT}} + c_e \cdot t_0\right) + $$

$$+P_{SC} \cdot \frac{S_M^2}{S_{rT}^2} \cdot \left(\frac{c_p}{T_{NOT}} + c_p \cdot \tau\right) \quad (3)$$

where: P_0 is the power losses in the core of the transformer; P_{SC} is the power losses in the windings of the transformer; T_{NOT} is the normal operation time (for amortization) [years]; c_p is the cost for 1kW installed [€/kW]; c_e is the unit cost of generating a kWh of electric energy [€/kWh]; τ represents the time used to determine the energy losses, with the operation time t_o (maximum 8760h/year); $\frac{S_M}{S_{rT}}$ represents the transformer flow-ratio for annual maximum load.

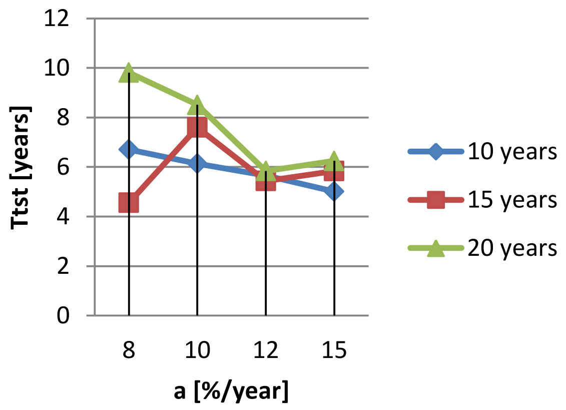


Figure3. The value Tst according to discount rate for three-periods of study (ts = 10, 15, 20 years).

The value Tst for discounted costs calculation. The value Tst for discounted costs calculation is defined in [9] and shown in figure 3 for three period of study:

$$T_{st} = \sum_{j=1}^{t_s} \frac{1}{(1+a)^j}, \quad (4)$$

where j represents the current year, t_s represents periods of study, and a is the discount rate, expressed in %/year. The analysis is done for a substation (electrical node).

The power and energy losses are basically produced only in the area of the busbar collector; the value of the costs regarding these losses is very low compared to the other categories of costs, so the differences among the various suggested solutions will not influence their ranking.

Therefore, the cost of power and energy losses in transformers or autotransformers C_{PEyear} can be disregarded.

The simplified calculation formula (1) is:

$$PTDC = CI + \left(C_{OMMyear} + CP_{year}\right) \cdot T_{st} \quad (5)$$

The optimal solution is considered to be the solution with the minimum present total discount cost. The results are systematized in a result table like Table 2, in which are specified all component costs in order to highlight the cost categories that favoured the optimal solution.

Table 2. The centralization of the results

Switching Scheme Solutions	1BC	2BC	…	…
CI **[10^3 €]**				
$C_{OMMyear}xT_{st}$ **[10^3 €]**				
$P_{year}xTs$ **[10^3 €]**				
PTDC **[10^3 €]**				

For small differences (<5-10%) among the first solutions in the hierarchy, the selection of substation switching scheme is the results of many aspects, including intangibles as personal preference, experience and judgment.

4. Proposing a calculation algorithm for the cost of penalties for non-delivery of power energy. Socio-technical point of view

At the core of all electricity services is electrical energy. Power systems are becoming increasingly integrated with other key sectors and critical infrastructure [24, 26, 27].

Usually, in substations various types of components are interconnected, such as: high voltage buses and structures, power transformer (or autotransformer), power lines, circuit breaker, voltage transformer, current transformer, lightning arrester, disconnect switch, control building, security barrier, protective relays and SCADA systems, grounding systems, communication protocols (substation IT architecture standards, including IEC61850) and optical sensors. For each of them the fault rate may vary [10, 25].

Weather events and fire are the leading cause of power outages [22, 28] (Figure 4).

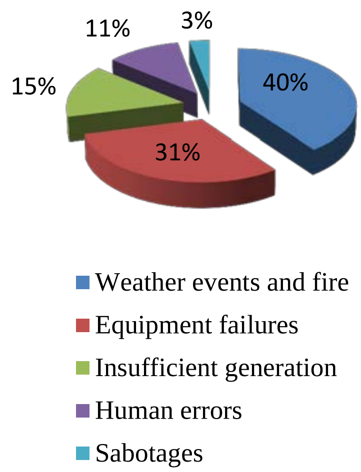


Figure 4. Major Outage Events with Loss of Electric Service, adapted from [23].

Coupled with the fact that most transmission and distribution (T&D) lines in service today were constructed during the 1960s and 1970s and were not originally engineered to meet today's demand or withstand severe weather raises concerns of congestion, distribution, reliability, and cost of service outages due to aging infrastructure coupled with severe weather can be a massive expense for the utilities.

Predictive reliability level is determined by the frequency of interruptions in the past and by the level of socioeconomic development and social welfare.

Penalties for non-delivery of power energy can imply a great range of values depending on the relative importance (Figure 5): (a) type of consumer, such as industrial, commercial, residential and contracts; (b) technology, infrastructure, operational processes, procedures and interruption characteristics (such as interval, extent, advance notification or not, time of occurrence, etc); (c) weather events (snow/ice storms, hurricanes, floods etc.).

Figure 5. The socio-technical perspective for multi-level interactions an electrical substation process

We calculate: cost of the penalties caused by unplanned disconnections ($P_{year-unpl}$) and by planned disconnections ($P_{year-pl}$).

From the point of view of disconnections, the analysis of no electricity supply can be divided in two zones. These zones are demarcated according to figure 6, on this showing:

- *The zone of busbar collector zone* (symbolized by the superior index ^{1}): any disconnection in the BC zone determines the indisponibility of the whole node (BC); accordingly, we will mark the afferent disservices with $P^{(1)}$;
- *The cells zone* (symbolized by the superior index ^{2}): any disconnection in the zone of a cell determines the indisponibility just of that circuit; accordingly, we will mark the afferent disservices with $P^{(2)}$.

For the calculation of the cost of penalties for non-delivery of power energy, there can be made some simplifying hypotheses, which allow a more rapid estimation of them, without affecting the credibility of the obtained solutions:

– In the case of planned disconnections, all the cells of a substation will be repaired one at a time (there are not considered more working teams simultaneously);

– In the case of disconnections in substations equipped with couplers (longitudinals, transversals, bypassing or with multiple functions), the maneuvre and separation /elimination time of an incident can be approximatively 2 hours/disconnection.

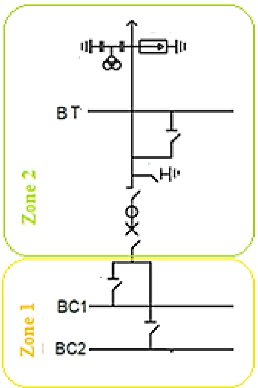


Figure 6. Demarcation example of the two zones of a cell (in switching scheme solutions with 2BC+B$_T$) for the calculation the penalties for non-delivery of power energy.

The modification of penalties for the non-delivery of power energy (as a consequence of the modification of the schema of connections) is thereby produced: practising the bypassing leads to reducing the non-delivery of power energy in the cells zone; practising a large number of busbars collector sections leads to reduced non-delivery of power energy in the BC zone.

The general formula of calculation to annual penalties for the non-delivery of power energy, expressed in €/year, is:

$$P_{year} = S_{med\ non-delivery} \cdot t_{non-delivery} \cdot d_{sp} \quad (6)$$

The calculation is made in a distinct manner, for the BC zone and for the cells zone and is expressed in €/year. Further, it is necessary to impose several specifications concerning the calculation of the terms from (6) relation.

4.1 The Non-Delivery Electrical Power

The medium nondelivered power, expressed in MVA, depends on the maximum electric load for longer time duration and maximum usage time per year:

$$S_{med\ non-delivery} = \frac{S_{M\ non-delivery} \cdot T_{SM}}{8760} \quad (7)$$

The energy transit differs, depending on the location where the nondelivery is calculated (the busbar collector zone or the cells zone).

Depending on the type of disconnection, these values can modify, thus: for unplanned disconnections it is working with $S_{med\ non-delivery}$; for planned disconnections there can be done the hypothesis of dealing with the consumers ($S_{med\ non-delivery}$ can be considered 30-40% of the previous value).

4.2. The Non-Delivery Time

In general, the nondelivery time, expressed in €/year, can be estimated with the following relation:

$$t_{non-delivery} = \lambda \cdot t_{intr} \qquad (8)$$

in which: λ - the intensity of damage or the medium number of defects in a year [disconnections/year]; t_{intr} – the medium duration for a disconnection, expressed in hours/disconnection.

For a solution different from 1BC, t_{intr} can be the maneuver time. The relation is identical for planned disconnections and for unplanned disconnections.

The durations are calculated separately, for the busbar collector zone and for the cells zone, taking into account the following indications.

4.2.1. The Non-Delivery Time in case of inavailability in the busbar collector zone

We determine the number of busbar collector steps (n_{BC}) and the number of disconnectors (n_D), for which we have:

$$n_{BC} = n_D \qquad (9)$$

Whichever BC steps and whichever disconnectors from the busbar collector can become inavailable during the exploitation, so the respective unitary durations must be summed for determining the total duration of nondelivery in the busbar collector zone, for the two categories of disconnections expressed in hours/year and BC zone:

$$t_{unpl}^{(1)} = n_{BC} \cdot t_{unplBC} + n_D \cdot t_{unplD} \qquad (10)$$

$$t_{pl}^{(1)} = n_{BC+D} \cdot t_{BC+D} \qquad (11)$$

In which the durations are obtained from statistical information, and at the planned disconnections it is considered that the revision of the disconectors from the busbar collector and the step busbar is made simultaneously.

4.2.2. The Non-Delivery Time in case of inavailability in the cells zone, [hour/year&cell]

For Un ≥ 110 kV (figure 5), the usual elements for a cell are the circuit breakers, switch mechanism of the circuit breakers, three current transformers, three single-phase separators, three monophase voltage transformers, surge arrestors, earthing switch. We determine the disconnection duration for every cell, taking into account the elements that a cell is composed of:

$$t_{unpl}^{(2)} = \sum t_{unpl\ elements} \qquad (12)$$

$$t_{pl}^{(2)} = \sum t_{pl\ elements} \qquad (13)$$

Under the hypothesis of reviewing the circuits simultaneously with the cell, we will have:

$$t_{pl}^{(2)} = 0 \qquad (14)$$

4.3. The specific disservice in electric service

The specific disservice (d_{sp}) can be expressed in relation to the cost of energy (c_e): for unplanned disconnections: d_{sp} is a multiple of c_e; for planned disconnections: d_{sp} can be chosen as a lower value (for example, in percentage value, 25% of the previous value).

The values of specific disservice produced by no supply differ for: the nondelivery in the system ($d_{sp} = c_e$) and for the nondelivery to the consumer (multiple for the cost of energy, depends the designing hypotheses).

4.4. Penalties for Non-Delivery of Power Energy

4.4.1. Annual Penalties for Non-Delivery of Power Energy in case of inavailability in busbar collector zone, [€/year]

$$P_{year-pl}^{(1)} = \sum S_{med\ non-delivery\ pl} \cdot t_{pl}^{(1)} \cdot d_{sp} \qquad (15)$$

$$P_{year-unpl}^{(1)} = \sum S_{med\ non-delivery\ unpl} \cdot \cdot t_{unpl}^{(1)} \cdot d_{sp} \qquad (16)$$

$$P_{year}^{(1)} = P_{year-unpl}^{(1)} + P_{year-pl}^{(1)} \qquad (17)$$

4.4.2. Annual Penalties for Non-Delivery of Power Energy in case of inavailability in the cells, [€/year]

$$P_{year-pl}^{(2)} = \sum S_{med\ non-delivery\ pl} \cdot t_{pl}^{(2)} \cdot d_{sp} \qquad (18)$$

$$P_{year-unpl}^{(2)} = \sum S_{med\ non-delivery\ unpl} \cdot \cdot t_{unpl}^{(2)} \cdot d_{sp} \qquad (19)$$

$$P_{year}^{(2)} = P_{year-unpl}^{(2)} + P_{year-pl}^{(2)} \qquad (20)$$

4.4.3. Total Annual Penalties for Non-Delivery of Power Energy, [€/year]

This penalties are given by the sum of the damage to the BC area and the damage to the cell area:

$$P_{year} = P_{year}^{(1)} + P_{year}^{(2)} \quad (21)$$

Observation. The damage calculation can be systematized in the form of Table 3. Increasing costs at electric power suppliers, due to adoption of some measure of improvement the electric power supply quality can be balanced by increase of the turnover, by increase of the sale of electric power or by increase of the selling price optim.

Table 3. The Cost of Penalties for Non-Delivery of Power Energy decision rules

5. Study case

5.1. Research question

The U_1 voltage substation, with the voltage of 400kV, is interleaved into a loop in the transmission or distribution network of an energy system by means of two overhead electric lines LEA_1 and LEA_2 having each section s = 300mm^2 and the lengths L_1 = 180km and L_2 = 220km.

The station with voltage U_2 of 110kV is powered only by the power station U_1.

The input of the power system in the case of three-phase short-circuits on the stations of 400kV is of the order I_{scc1} = 29kA and I_{scc2} = 35kA.

At the busbars collector of 110kV, an electric demand is estimated, characterized by:

- Duration of Maximum Load Ability: S_M = 217MVA;
- Annual Use Usage: T_{SM} = 6000 hours/year.

5.2. Objective

It is desirable to supply safe, quality and economical efficiency, from the point of view of socio-technical services, with the electric power (W, S_M) of consumers connected to U_2.

5.3. Solutions

3

Taking into account the S_M, we identified three technically possible solutions for the 400/110kV transformer. The most appropriate variant, according to the imposed restrictions, for a = 10%, is 1T x 320MVA.

Following the analysis of the data resulting from the calculation of the short-circuit currents on the electric busbars collector [12], no limitation measures for Issc are required because at any other point (on the electric lines, etc.), the short-circuit currents are lower than those calculated on the busbars substations.

The results of short circuit calculation are also used to select switching devices, adjust protection, and ensure electromagnetic compatibility.

We proposed and analyzed:

- 5 variants of connection schemes for the 400kV substation:

Zone	1: busbar collector		2: cells	
Switching Scheme Solutions	$P^{(1)}_{year-pl}$	$P^{(1)}_{year-unpl}$	$P^{(2)}_{year-pl}$	$P^{(2)}_{year-unpl}$
1BC	**m**	**n**	**p**	**q**
1 BCS	**m1**	**n1**		
2 BC	**0**	**n2**		
1 BC + B_T	**m2**	**n3**	**0**	**q1**
2 BC + B_T	**0**	**n4**		
……..				

  - *Open-Terminal Air-Insulated - AIS*: single busbar collector (1BC), one breaker – double busbar collector (2BC), ring bus and 4 breakers for 3 circuits, shown in Figures 7-10.
  - *Metal-enclosed Gas Insulated - GIS*: Single busbar collector (1BC), shown in Figure 11.
- 3 variants of connection schemes for the 110kV substation:
  - *Open-Terminal Air-Insulated - AIS*: single busbar collector (1BC), shown in figure 12 and One breaker - double busbar collector (2BC), shown in Figure 14.
  - *Metal-enclosed Gas Insulated - GIS*: Single busbar collector (1BC), shown in Figure 13.

For all of these schemes, we applied the reasoning outlined above. Calculations can be done with specialized programs.

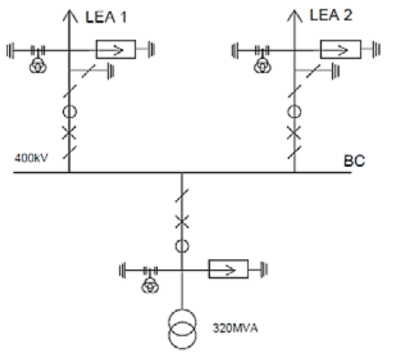


Figure 7. A single bus configuration, AIS, 400kV.

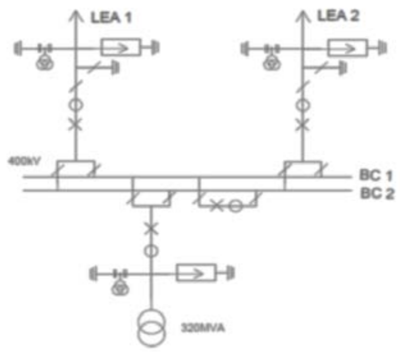


Figure 8. An breaker - double bus configuration, AIS, 400kV.

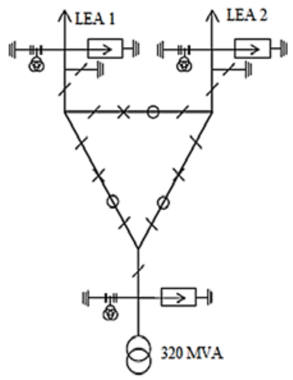


Figure 9. Ring Bus (polygon), AIS, 400kV

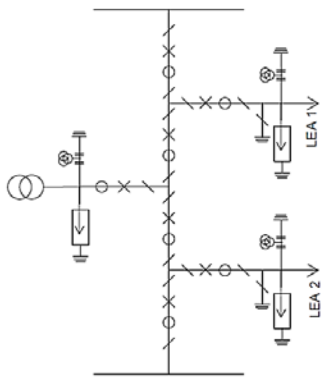


Figure 10. Four breaker for three circuits (1.33breakers/circuit), AIS, 400kV

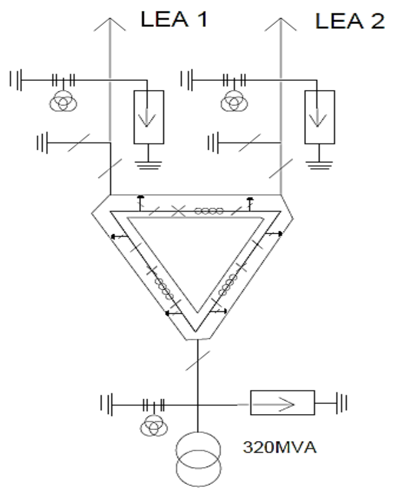


Figure 11. Ring bus (polygon), GIS, 400kV

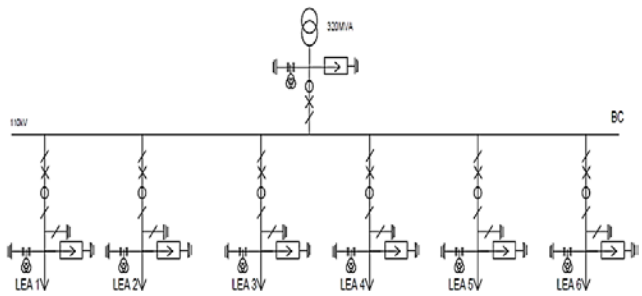


Figure 12. Single bus , AIS, 110 kV

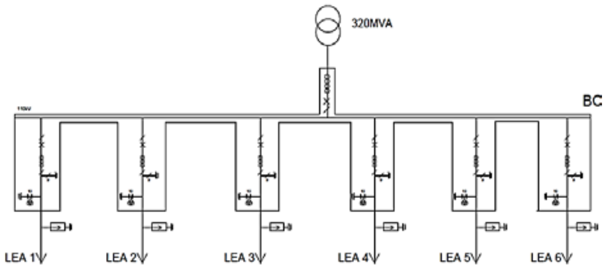


Figure 13. Single bus , GIS, 110 kV

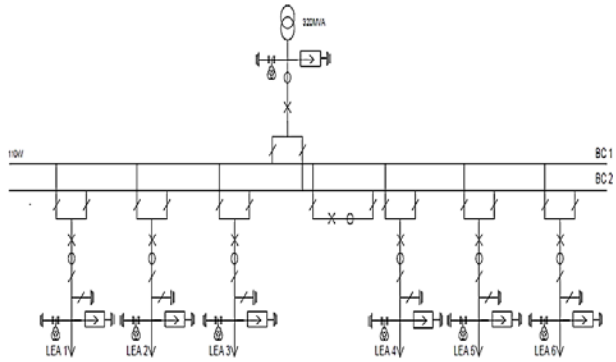
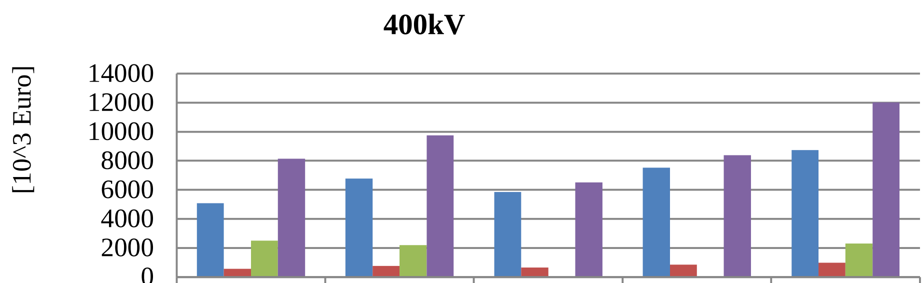
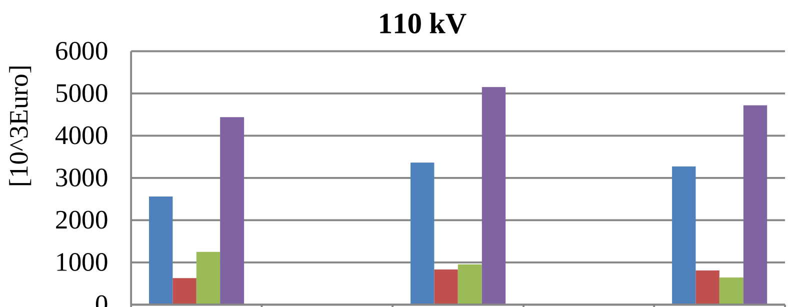


Figure 14. Double bus, AIS, 110 kV



	1BC	2BC	Poligon (AIS)	Poligon (GIS)	1.33Breaker/Circuit
CI	5067.84	6780.56	5854.64	7521.16	8726.4
COMMyear x Tst	567.09	758.75	644	841.62	976.48
Pyear x Tst	2510.25	2203.67	12.26	12.26	2307.91
PTDC	8145.18	9742.97	6510.9	8375.04	12010.8

Figure 15. The centralized results for PTDC in 400kV substation



	1BC (AIS)		1BC (GIS)		2BC
CI	2560.88		3365.84		3272.8
COMMyear x Tst	630.4374		828.602		805.6979
Pyear x Tst	1250.83		956.52		639.3952
PTDC	4442.15		5150.96		4717.89

Figure 16. The centralized results for PTDC in 110kV substation

5.4. Results

According to the centralized results in Figure 15 and Figure 16, the optimum solution for the 400kV substation is the one with the AIS ring bus, and the optimal solution for the 110kV substation is the one with 1BC, AIS.

The selection of the optimal schemes for each voltage level leads to the single-line diagram illustrated in Figure 17.

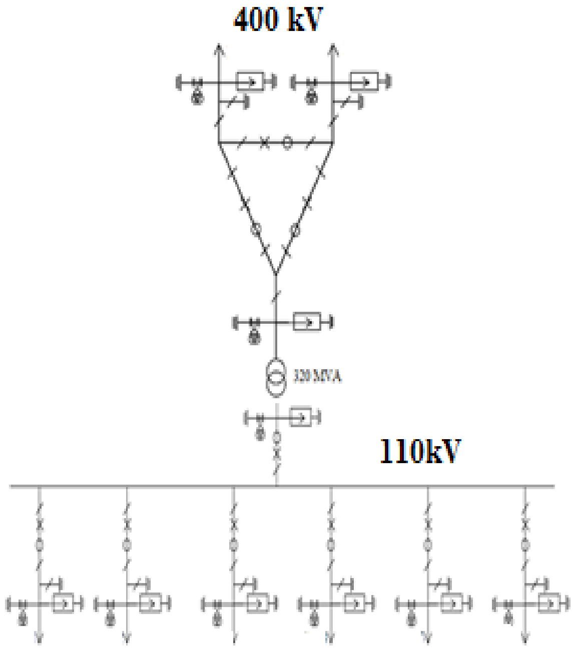


Figure 17. Single-line diagram illustrates the optimal solution of the 400/110kV station, designed from the point of view of the socio-technical systems

6. Conclusion and Future Directions

The power stations in the power plants are socio technical systems of high operational responsibility, especially in the new deregulated and competitive environments.

The cost savings and environmental pressures on utilities will cause utilities to run their networks and substations closer to the design limits of the equipment.

A key problem in many organisations that we believe that represents a significant contributor to system failures is the fact that there are often only weak links between change processes and system improvement processes.

In this paper, we have analyzed the decisions regarding the designing of the electrical substations for the evacuation of the electrical energy produced in a power plant the quantification from the point of view of socio-technical services.

Section 4 is devoted to a calculation algorithm for theoretical cost of penalties for non-delivery of power energy. In section 5, we applied the proposed algorithm for a hypothetical but still semi-realistic study case (400/110 kV substation). The results of the calculation were integrated into the economic criterion considered in section 3 for collaborative decision making modeling.

The method proposed is to be a key part of a larger setup.

Our immediate goal is to apply the methodology to a real modeling session for refurbishing substations.

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