

TFC 2015 – TRIZ FUTURE 2015

## A new set of measurement standards for a circuit breaker application

Davide Russo\*, Christian Spreafico

*University of Bergamo, Via Marconi 5, 24044 Dalmine, Bg, Italy*

\* Corresponding author. Tel.: +39 0352052353; fax: +39 035 2052077. E-mail address: [davide.russo@unibg.it](mailto:davide.russo@unibg.it)

### Abstract

During the years, the Standard Solutions (SS) have been reformulated multiple times, through redefinition, simplification and exemplification. The original 76 Standard Solutions are grouped in classes. The fourth class contains the standards for measuring and seems to be the less investigated.

In this paper, the standards related to problems of measure are reformulated and classified into three main groups: (1) direct measuring of the desired parameter, (2) changing the problem in order to not measure it and (3) obtaining an indirect measure of the desired parameters.

To be more systematic, a rigorous ontology drives the user to define what has to be measured (field or substance), where (internal or external to the system) and how (exploiting an already existing resource or if a new substance/field has to be introduced or if already present). Authors applied the new approach in several industrial application. A case study, involving a multinational company in the field of high-tension vacuum circuit breaker, is proposed and discussed to highlight strengths and limitations of this new set of standards vis a vis the classical Standard Solutions. TRIZ experienced PhD students from the University of Bergamo repeated this test so as to have another point of view for this comparison.

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Peer-review under responsibility of Scientific committee of Triz Future Conference

*Keywords:* Standard Solution, Triz, Measure, Information Retrieval

### 1. Introduction and State of the Art

This paper deals with measurement problems. The most widespread approach to perform a correct measure is to identify the right parameter(s), apply the better instrument and the most suitable method in a direct measurement. The choice of the more suitable combination of target/tool/method requires people skilled in measurement technology and has to take into account all the constraints of a certain situation (i.e. time, space, costs, etc.).

TRIZ standard solutions help users every time a direct measure is not possible, but do not suggest anything when the user does not have enough experience.

TRIZ standard solutions class 4 [5] are one of the tools that help to face the measurement problem from another perspective: they try to change the problem or the target parameter to be measured.

In the traditional form, class 4 is organized in the following subgroups:

- Introduction of indirect measurement methods (3 solutions);
- Creation of a measurement system (4 solutions);
- Enhancement of the measurement system (3 solutions);
- Measurement of the ferromagnetic-field (5 solutions);
- Direction and evolution of the measuring systems (2 solutions).

In addition, we have the following general suggestions:

- Try to change the system so that there is no need to measure/detect;
- Measure a copy;
- Introduce a substance that generates a field (introduce a mark internally or externally).

Since their introduction, several efforts have been spent to improve them, in order to overcome the difficulties in their

application. Some authors (such as [6], [7]) have proposed new guidelines with the aim of facilitating the use of the guidelines. Others have instead reformulated the standards themselves, by providing new notations [8] or new classifications [9]. Still others have reinterpreted the standards by using other tools related to TRIZ theory, like the laws of system evolution, or outside TRIZ as the Energy Material Signal EMS model [10]. Several efforts have also been spent in reducing the number of standards as well as the number of classes: [11], [12] and [13] proposed three main classes: improving the system with little or no change; improving the system by changing the solution; detection and measurement.

TOP model and a graphic approach (i.e.[14],[15]) have been combined with a new tool called Film Maker to manage the cause-effect chain in [16]. However, despite the multiple reformulations during the year, the instrument still struggles in application of everyday engineering practice. Moreover these works have only marginally interested the fourth class of standards.

In this paper we propose a scheme, derived by the Altshuller's Standard Solutions that can be applied alongside them or in substitution.

The structure of the paper is as follow. Section 2 presents the new set of Standards Solutions; section 3 contains our approach based on the new Standard Solutions; in section 4 the case study is presented; section 5 a discussion on the new system in comparison with the original one; section 5 draws conclusions.

## 2. IR for supporting Standard Solutions application

In order to increase the efficacy in applying the Standard Solution application, knowledge bases collecting technologies and physical effects can be integrated in order to suggest the user more alternatives.

Two different strategies are today available for retrieving needed information:

- Searching by structure. Where keywords and concepts are associated with an object or artifact. For instance, in order to measure the length, we search the name of the tool required to measure it, such as "meter". This is the most common method used to find a technology on web catalogues, patents or scientific papers. Some tools similar to meter, like the ruler or the caliber will be easy found, but alternative technologies such as laser or Doppler Effect have less probability to appear in the searches.
- Searching by function. It is a search methodologies where instead of searching an object we search for what it does. As theorized by Litvin in Function Oriented Search-FOS method, the couple VERB + OBJECT, is the typical research strategy for searching in patent database. In this case we search a technology through the functionality performed, generally "to measure" or "to detect" + the object or the parameter to be measured (i.e. "measure length"). According to several studies [1], [2], this can increase the overall recall, potentially finding a larger number of technologies based on the same function.

Pointers to effects, and more in general Physical Effect (PE) databases can be a valid support to ameliorate quality of search results. For example KOM methodology [1] combined functional search with physical effects creating a new triad "function + object + PE" as a search target, so obtaining a classification of known and still unknown technologies according to the different PE used for realizing the measure.

When searching something, whether it is structure, V+O couple or V+O+PE triad, semantic expansion of all terms composing the query is a very efficient way for increasing the degree of effectiveness. Also in this case several tools may help (i.e.[3], [4]).

Whatever the strategy adopted so far, Information Retrieval based techniques do not solve all problems. Searching by structure or by function allows a very precise analysis but offers a series of result which is strictly related with the source of knowledge in which we are searching; PE databases are a very powerful mean to discover new unknown directions but it works at a very high level of detail making the resolution of the measurement problem very difficult.

## 3. A new approach for applying Indirect measure

The proposed schema organizes all the suggestions into three main groups that express how we can perform a measure:

- Direct measure of the interesting parameter X: it is only implicit in traditional Altshuller's class 4.
- Do not measure the parameter X: derives from the standards #4.1.1.
- Indirect measure: measure a parameter Y influenced by X: contains all the other standards, reorganized and reassumed in accordance with the formalism of substance and field.

In this paragraph, we specifically discuss about the "Indirect measure" class of the new classification, explaining the reasoning through which we have reach the current formulation.

Firstly, we must understand the meaning of relation between parameters and indirect measure. In logical-mathematical language, two parameters X and Y are related if  $Y=f(X)$  or  $X=g(Y)$ , where the first one is named "dependent" parameter, the second one is "independent" and f is an expression that explains the linkage between them. While we perform a measure on a certain physical phenomenon (i.e. the degree of vacuum) or a physical object, X is a parameter that describe it and that we want to measure (i.e. the pressure of the gas inside an ampoule). Y is instead another parameter of the same phenomenon/object that we really measure because is more detachable than X. Given Y, we can obtain X through the expression  $Y=f(X)$ .

On the nature of the relation  $f(X)$  depends the degree of correspondence of the measure on X. The function f can be an analytical or a numerical expression that in case introduce a certain error on the derivative measure; other errors are introduced in the direct measure of X and Y.

In this paper, we are not interested in discussing the theory of measure but only in providing a method to support the mapping of the possible systems for the measure.

Another clarification about the nature of X and Y regards the measured quantity. If we are interested on the absolute quantity (i.e. “measuring the value of the pressure of a gas”) we have to consider entirely X and Y; while if we are interested in a variation of the standard state (i.e. “measure the overpressure caused by ...”) we consider  $\Delta X$  and  $\Delta Y$  and the relation between the two factors will be  $\Delta Y=g(\Delta X)$ , where the relation g is not necessary equal to f. This second situation is more used when detecting the anomalies of a system.

For the explanation of the proposed method and for its use, the differences between X and  $\Delta X$  is not important, while it is important for the evaluation of the systems suitable for the measure. In the rest of the paper we use X and Y simply to describe the absolute and the relative quantities.

3.1. Indirect measure classes

The class for indirect measures has been divided into two

the capability of measurement: an added substance can be introduced in the system if it is more detachable than other.

Moreover the substance and the field can respectively influence another field or substance, so we can measure a third parameter Z, in turn linked to Y and consequently to X and so on, building chains of alternating substances and fields. The advantage of indirect measure of a further substance and field depends on the possible greater ease of measure. For this reason, if we choose this way, the substance or the field that we will introduced in the system should be more detachable.

Notice that this classification does not mentions where/when the measurement take place (i.e. inside or outside the system). As a matter of fact, a proper combination of introduced substances and fields allow us to provide the measure where and when it is more comfortable (e.g. a remote wireless communication to measure parameters in dangerous places).

Regard the evaluation and the choice of the best instrument of measure, the discussion is more complex, often involving not technical criteria but more marketing and political choices, such as normative and various constraints.

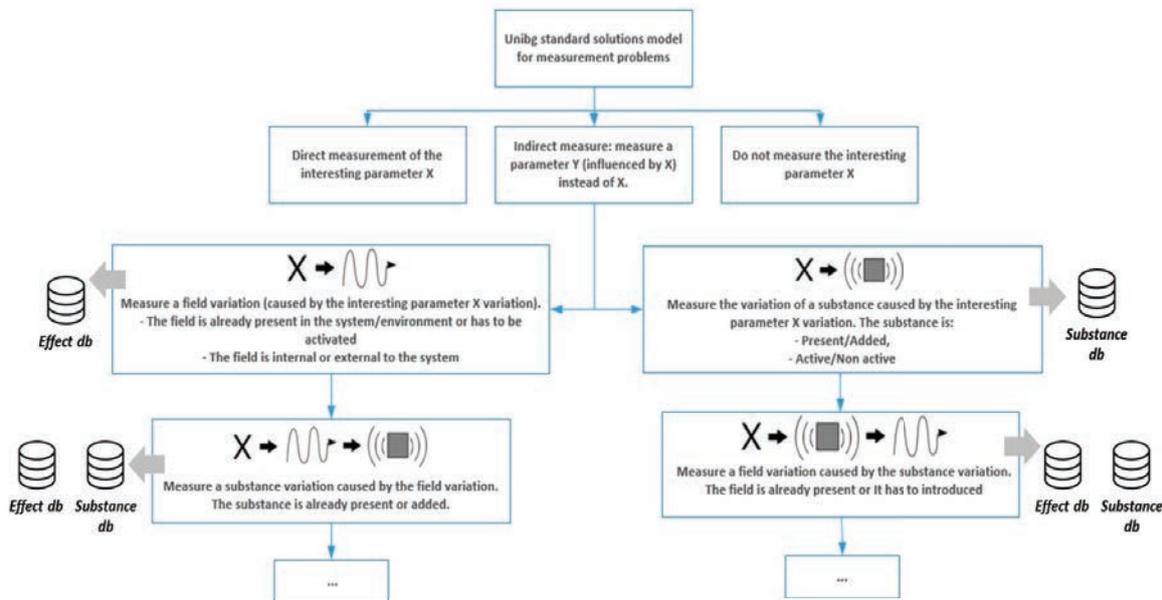


Fig. 1: The proposed schema

other minor subgroups by referring to the notion of substance and field:

- 3.1 Measure a field parameter Y, where the field is directly influenced by the parameter X;
- 3.2 Measure a substance parameter Y, where the substance is directly influenced by the parameter X;

The field and the substance can be internal or external to the system if they are already present or they have to be added. The choice between the two possibilities depends on

4. Case study

In order to provide a practical example of what explained, we propose a case study on the measure of the degree of vacuum inside the ampoule of a vacuum circuit breaker.

The considered appliance allows to separate an electric power line when a fault occurs or for maintenance operations.

The response of the system must be immediate (around ms). Inside the circuit breaker, two conductive copper rods are coaxially and vertically disposed inside an ampoule and they are connected to two branches of the power line. During the opening, the inferior rod is lowered by a transmission and a motor. After the opening a gap of about 10 mm remains between the rods; the vacuum in this volume extinguishes the electric arc that is from a rod to the other.

To guarantee the correct functioning of the system, the vacuum conditions play a fundamental role. For this reason, we have to measure its integrity several times during the operative life of the circuit breaker.

In the rest of the chapter we show how the schema helps us in determining what technologies we can use to achieve the goal.

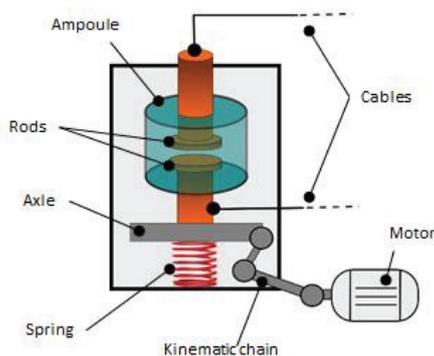


Fig. 2: Schematic representation of a circuit breaker (one phase).

#### 4.1. Direct measure of the interesting parameter and do not measure

The first two groups of the proposed schema are the same of the traditional standard solutions. According to them:

SS 1: if we want to measure the vacuum degree or the gas pressure inside an ampoule, we can search “by structure” looking for pressure measurement instruments. For example searching “barometer” or “vacuometer” in order to see if somebody as already used it inside the ampoule.

SS 2: “Do not measure the vacuum inside the ampoule” suggests instead to change the problem so that the measure of the vacuum is no longer necessary. In this sense, a possible solution is the substitution of the vacuum inside the ampoule with a gas or a liquid able to extinguish the arc like the vacuum itself.

#### 4.2. Indirect measure of the interesting parameter

According to the proposed schema, instead of directly measuring the vacuum degree, we can also measure a field or a substance parameter influenced by the variation of the vacuum degree itself, and indirectly derive the measure of the vacuum.

To do this, we can use one of the available collection about fields such as the one of Table 1, or adopting most powerful tools based on function searching.

#### 4.2.1. Measure a field already present in the system

SS 3.1: In this case we have to find what fields, between the presents in the system, can be influenced by the variation of the vacuum degree. Without list them all, one of them is the current inside the rods, which can increase or decrease depending on the loss of the vacuum inside the ampoule. Its measure provide us the base to derive the interesting parameter.

In case we are not able to measure this parameter we can pass to the next step.

Table 1. Partial list of fields and physical effects

PARTIAL LIST OF FIELD/PHYSICAL EFFECTS		
<b>Mechanical</b>	<b>Electric</b>	<b>Thermal</b>
Ablation	Electrical	Heating
Abrasion	Electrostatic Discharge	Thermal-expansion
Erosion	Eddy-Currents	Regelation
Brush	Electric-Arc	Conduction
Friction	Electrical-Discharge	Freezing
Brinelling	Corona-Discharge	Cryolysis
Force	Machining	Incandescence
Centrifugal Force		Intumescent Materials
Compression Force	<b>Acoustic</b>	
Impact Force	Ultrasound	<b>Electromagnetic</b>
Gravity		Laser
Deformation	<b>Magnetic</b>	Electromagnetic-
Resonance	Pulsed Magnet	Infrared Radiation
Fatigue	Induction	Radiation
	Ferromagnetic	Light
		Joule-Lenz Effect

SS 3.1.1: the measure of a substance influenced by the selected field (electric current). Between the substances present in the system, the rods themselves can helps us: the current passage inside them cause a heating generation according to Ohm’s law. So, through the measure of the rods temperature we can derive the measure of the field (electric current) and in turn calculate the vacuum degree inside the ampoule. Alternatively, we can also add a new substance in the system, by choosing a substance that is more sensible to the current passage than the rods, and eventually measure its temperature.

As we did for already present fields, we can do the same for added fields and substances, as illustrated in table 2.

## 5. Discussion of the results

The generation of different solutions involved a first meeting with a group of industrial experts and a second back office work with TRIZ experts. A great number of solutions have been found in both sessions and a deep investigation is followed for each one.

The staff of the first meeting was composed of 10 industrial researchers with a narrow TRIZ background, with different Research and Development areas (mechanical, electrical and electronic engineering), coming from different countries (Italy, Germany, US, China, India).

The presented case study is only a synthesis of one of the measurement problems faced with the proposed approach respect the entire set of other measures related to prognostic function. The founded results have been collected in mind map infographics and presented to other industrial researcher during an internal workshop. The approach has been positively accepted and some solutions have been selected for future developments.

The same exercise has been reassigned in a research project with researcher from the University of Bergamo.

These researches came from different areas of Research and Development (mechanical, electrical and electronic engineering) and have knowledge of TRIZ at different levels as follow:

- 4 Academic researchers with TRIZ experience: researchers and PhD students involved in product and process innovation from different points of view, engineering design, problem solving and CAE methods;
- 5 Academic researchers without TRIZ background: researchers and PhD students belonging to the branch of

mechanical engineering and biomechanics, working with CAD and FEM analysis;

By the application of the method, the following observation can be made.

TRIZ Academic researchers apply the method in a more effective way, probably due to previous knowledge of the standard solutions mechanisms.

Industrial researcher are instead more oriented in finding and defining solutions that can be applied directly to their case, highlighting drawbacks of proposed solutions and trying to immediately solve secondary problems. This behavior lead to a smaller number of solutions but with higher feasibility.

The use of the method, both for academic and industrial researches seems to guarantee an acceleration in the idea generation process. This effect is more evident for industrial researchers. Both experts and not experts found many difficulties in finding solution on the second level, however these solutions are the most interesting because most of them had not been found by groups using traditional Altshuller's class 4.

## 6. Conclusions

In this paper, a new organization of Altshuller's standard

Table 2. Examples from the case study

1st step		2nd step			
SS 3.1 Measure a field already present in the system	Electric Field	Measure the variation of the current parameters (intensity and voltage) inside the rods caused by the variation of the vacuum degree	SS 3.1.1 Measure a substance already present in the system	Thermal Heating	Measure the variation of the temperature of the rods caused by the variation of the current inside them
	Magnetic Field	Measure the variation of magnetic field (wave parameters) around the rods (see Lenz law) caused by the variation of the vacuum degree	SS 3.1.1 Measure a substance introduced in the system	Light Radiation	The variation of the vacuum state causes the rotation/translation/deformation of a mirror that reflects the magnetically field in different manner
SS 3.1 Measure a field introduced in the system	Electromagnetic Radiation	Measure the variation of the x-rays through the ampoule			
SS 3.2 Measure a substance already present in the system	Thermal Expansion	Measure the ampoule dilatation by the variation of the vacuum degree	SS 3.2.1 Measure a field already present in the system	Light Radiation	Measure the variation of the reflection angle of the natural light caused by the dilatation of the ampoule
			SS 3.2.1 Measure a field introduced in the system	Infrared Radiation	Measure the variation of the reflection angle of a laser
SS 3.2 Measure a substance introduced in the system	Deformation	Measure the translation of a plate inside the ampoule caused by the variation of the vacuum degree	SS 3.2.1 Measure a field introduced in the system	Electric Field	Measure the variation of the current in an introduced electrical circuit with a resistance with variable length rigid with the position of the plate

solutions for measurement and detection problems has been proposed. This work aims at better reorganizing standards in order to facilitate its application in R&D departments to screen alternative technologies and to solve measurement and detection problems. In the proposed approach, standards have been divided into three main groups: direct measure; do not measure; indirect measure.

A rigorous ontology drives the user into indirect measures, to define what has to be measured (field or substance), where (internal or external to the system) and how (exploiting an already existing resource or if a new substance/field has to be introduced or if already present).

A case study about the measure of the degree of vacuum inside a medium voltage circuit breaker has been proposed to facilitate the comprehension of the method. The case study comes from a real industrial application and revealed interesting consideration about differences between TRIZ experts and industrial researchers.

Further developments of the proposed method will be concentrated on its integration inside a comprehensive TRIZ-based problem solving activity.

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