



# *Total Reliable Efficiency (TRE)*

*A global approach for continuous energy improvement*

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**Abstract** — During the last years all the productive sectors of the economy have been affected by a growing economic and environmental pressure. Fundamentally the productive sectors must confront every day with individual and global issues such as the followings. More and more stringent standards for environmental quality, related mainly to the reduction of greenhouse gases (GHG). Reach or to continue being economically competitive in the global market, which requires the reduction of production or services costs. Fulfill the requirements of quality and delivery times demanded by the customers. Continuous increase of energy prices, and the present tendency of constant increase of power consumption.

One of the best ways to manage this situation is to focus on energy efficiency, but not on the conventional approach related only to energy savings and the correlation between energy and process (intensity). It should be pointed out the reliability of the power supply, based on the criticality of the demand side (loads), even more if a continuous process is involved on the analysis. This affirmation is sustained by the fact that on this cases, an unexpected interruption of the energy supply will involve more inefficiencies (transient) than in a stationary operation.

The Total Reliable Efficiency (TRE) follows a methodology that involves energy consumption evaluation, basic process analysis and energy risk quantification, to obtain a ranking of

efficiency and risk reduction measures. Measures that enables to quantify and prioritize options and generate multiyear action plans and strategies.

*Keywords: energy efficiency, reliability*

## I. INTRODUCTION

Generally energy efficiency analysis focus only on energy savings and performance, but generally the studies assume that there is no interruption on energy supply. On the other hand, reliability studies focus on the criticality level of the distribution network and the availability of the energy supply, but in no case consider the inefficiencies related to oversized equipment, or components not included in the network.

Apparently both approaches are incompatible, but in fact that is not true at all. An unexpected interruption of energy supply in a continuous process will involve more energy inefficiencies (transient) than on its stationary operation. Also, when the focus converge only on availability then the energy performance of the installations falls to a second or third level of priority, and the experience says that this implies great hidden improvement opportunities.

Total Reliable Efficiency follows a methodology that complements both point of views, trying to embrace all the possibilities according to objective priorities.

## II. ENERGY EFFICIENCY ANALYSIS

As it was introduced earlier, right now energy is one of the main concerns of the companies, even if they are from the industrial sector or the commercial (tertiary) one. There are many reasons to explain the rising interest on this subject, but the principal one is energy prices, and the increase of the proportion of this cost on the overall production costs.

To handle this situation most of the companies are implementing energy monitoring systems (energy management systems) to recognize their actual energy consumption per production lines, per buildings, per technologies (compressed air, HVAC systems, steam generators, etc.) and have the necessary information to define ratios (specific energy consumption), objectives, and possible energy saving solutions and best practices. Also, most of them, are implementing automation systems to control and manage their installations focusing on energy efficiency criteria, guaranteeing production or comfort levels depending on the sector analyzed.

Although, reducing energy consumption requires energy efficiency studies to be performed by specialized consultants that provide independent advice. This studies take all the information available and complementing it with other specific on-site data collected during inspection or audits, to get more in deep on the evaluation of energy saving projects.

Generally energy efficiency studies focus on energy consumption and do not account, in any systematic way, for interactions between systems and equipments, or in other words, they do not address plant design or configuration (process integration).

### A. Diagnostics – Preliminary analysis

The preliminary analysis is called sometimes a diagnostic. This first phase of an energy efficiency analysis focus on a qualitative examination of the facility to identify immediate opportunities for savings, as well as equipment (technologies) or processes that require further examination.

The diagnostic develops the following tasks and objectives:

- On-site inspection of the facilities or systems (horizontal technologies).
- Description of the process and identification of the sector or areas of greatest energy consumption.
- Analysis of energy billing (water, gas, electricity, etc) and sub-billing.
- Evaluation of the evolution of the energy consumption and ratios (specific energy consumption)
- Energy balance of the facilities (Sankey diagram)
- Identification of opportunities of optimization.
- Evaluation of the strategic variables related to energy management.

- Definition of an audit plan focus on consumption, potential savings and customer priorities.

### B. Energy audits – Comprehensive analysis

Once the preliminary analysis has being done, generally energy audits are focused on the priority areas that were recognized to have possibilities to improve on energy efficiency (audit plan).

Energy audits are comprehensive and detailed analysis. Similar tasks as in the preliminary analysis are performed but focused on every single technology and process of a facility or building. The study includes also:

- Process analysis and identification of greater and critical energy consumers.
- Datalogging of the energy profiles and representative variables of the diverse equipment that conforms the installations.
- Energy balance for every technology and process included in the audit (Sankey diagram).
- Analysis of operational and maintenance strategies and policies.
- Engineering projects of energy performance improvement solutions (turnkey projects)
- Establishment of an optimization plan based on energy saving potential, required investment (financial analysis and ROI validation) and technical possibilities.
- Definition of the monitoring and targeting strategy necessary to assure the expected objectives.

### C. Efficiency Index

Energy audit enables qualitative and quantitative analysis to be performed to define the energy saving opportunities, the possible reduction of the specific energy consumption (intensity) or the possible increase on the energy performance of the installations.

Whatever the index used, it is clear that it is possible to define an efficiency index (EI) for every technology or process, or even a global index for the site studied.

$$EI = 1 - \frac{(AC - FC)}{FC} \quad (1)$$

This index represents the actual performance (actual consumption “AC”) against the optimal situation (future consumption “FC”) that is technical and economical feasible.

$$\%Savings = \frac{(AC - FC)}{AC} \quad (2)$$

When the installation reaches the expected energy savings, the resulting efficiency index (equation 1) equals one.

### III. RELIABILITY ANALYSIS

The quality of the energy supplied to the current consumers in an installation can be affected by various disturbances (frequency variations, sags, swells, harmonics, flickers, etc.) either imposed by the external supply network (electric grid) or generated itself within the internal distribution network. Poor quality generates malfunctions and even damages on the operating equipment. The type and cost of the possible damages depend both on the type of the consumer, and on the installation criticality level.

The criticality level for a energy consumer, in both the industrial and tertiary sectors, is related to its immunity to a brief or long loss of power. Thus, a momentary break in supply to a critical consumer can have serious consequences on the installation's operation without it being intrinsically affected.

Most of the time the immunity to loss power requires dedicated equipment such as uninterruptible power supplies or independent generators. But this equipment is generally not enough to solve all the problems. The network configuration, automatic power restoring control devices, the level of reliability of the equipment, the selectivity of protection devices and a strictly maintenance policy, all play a key role in minimizing, or even eliminating, down time.

Reducing the effects of power loss requires reliability studies to be performed by specialized consultants, taking into account all the mentioned factors, as well as the frequency and duration of the loss that is acceptable for each installation or consumer:

- **Vital:** installations that not tolerate the slightest break in supply. Normally connected to an uninterruptible power supply.
- **Essential:** consumers which must have the power restored to them after a few seconds of the failure.
- **Priority:** consumers that accept stoppages of several minutes long.
- **Non priority:** accepts a long break (hours) in power supply, until the external electric grid recovers its normal operation.

The reliability studies advises the final user for the best suited network configuration and equipment that minimizes the effects of a power loss, the proper reliability centered maintenance procedures and planning, and the most adequate energy supervising system to monitor the evolution of all the critical components of the network.

All together focused on the main objective, reduce the unavailability of the installation, reducing also the associated costs related to salaried expense, raw materials, customer penalties and commercial turnover.

#### A. Definitions

Before continuing with the explanation of the principal aspects of reliability studies, it is important to expose some

of the particular terms and definitions related to this kind of analyses.

- **Dependability:** is a generic idea that measures the quality of service, provided by a system, so that the user can have justified confidence on it.
- **Reliability:** is the probability that a unit is able to accomplish a required function under given conditions, during a given interval of time (t1,t2).
- **Availability:** is the probability for a unit that is in a state that enables it to accomplish a required function under specific given conditions and a moment in time (t).
- **Maintainability:** is the probability that a given maintenance action can be carried out within a period of time (t1,t2).
- **Safety:** probability of avoiding an event with hazardous consequences within a given period of time (t1,t2).
- **Failure rate:** probability that a unit or component loses its ability to accomplish a function during the interval (t, t+dt), knowing that this unit hasn't failed before that interval of time. Generally, the failure rate is not constant during the component life (see "Fig. 1"), but is assumed so ( $FR(t)=\lambda$ ) as a simplification of the model.

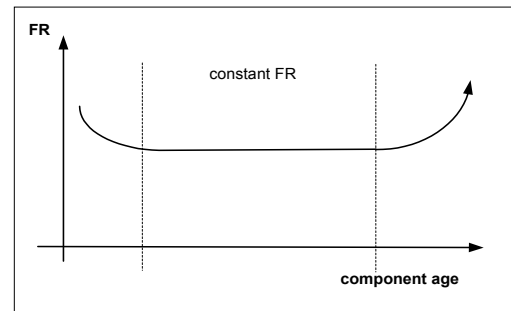


Figure 1. Failure rate. Bath-tube curve model

- **Mean Time to Failure (MTTF):** the average time of correct operation before the first failure.

$$MTTF = \int_0^{\infty} t \cdot f(t) dt = \lambda \int_0^{\infty} t \cdot e^{-\lambda t} dt \quad (3)$$

- **Mean Time Between Failure (MTBF):** average time between two failures in a repairable system.

- *Mean Up Time (MUT)*: average time of correct operation between two failures in a repairable system.
- *Mean Time to Repair (MTTR)*: average time to repair ( $\mu_{eq}$ ).
- *Mean Down Time (MDT)*: average time for which the system is not available. It includes the time to detect the fault, the time for the maintenance service team to get to the fault, the time to get the replacement parts for the equipment to be repaired and the time to repair.
- *Unexpected or undesirable event (UE)*: system critical failure that will lead to possible catastrophic damages (human, financial, ecological, ...), that must be analyzed in order for the user to feel justified confidence in the system.
- *Component unavailability  $U(h/year)$* : ratio of time per year in which a specific component of a system, or a system itself, is not available.

$$U = \frac{MDT}{MTTF + MDT} \cong \frac{MDT}{MTTF} = MDT \cdot FR \quad (4)$$

### B. Functional analysis

A reliability study begins with the functional analysis of the system or installation, describing in graphical and written terms the relations between the network, its constituent components and the energy consumers (process or technologies). Also the functional analysis describes the behaviour of the system, exposing the sequences of the various possible states and the events that can induce the system to change.

### C. Failure mode analysis

Related to the functional analysis, this second phase of the reliability study aims to determine for every component of the system their possible failure modes, their causes and consequences of occurrence and the failure rate associated to each failure mode identified (quantitative valuation).

### D. Reliability data

To bring to the study a quantitative valuation, it is also necessary to have probability data for the failure of the system's equipment. There are several sources of this data, reliability studies, failure statistics observed by utility companies and other manufacturers, IEEE database, etc.

Wherever the data come from is important to have in mind that generally the use of it is non-specific to a system being analyzed. Furthermore, the assumption (simplification)

of a constant failure rate ( $\lambda$ ) independent of the age of the equipment, provide the possibility to make valid comparisons between systems.

Also it is necessary to define the mean time to repair for every component, related to the company's maintenance policy and planning (inventory, frequency of preventive maintenance, type of maintenance contract, etc.), and the possible functional reconfigurations associated to the network architecture and control.

### E. Modelling

Knowing all the functional relationships between network, components and energy consumers, the possible failure modes determined during the previous analysis, and the standardized reliability data, the malfunctioning of the network can be represented by a model.

Modelling enables qualitative analysis of the network performance levels, by the search for common modes of simplest combinations that contribute to the appearance of an unexpected event. Also enables quantitative analysis calculating dependability criteria:

- Average number of hours that the system functions correctly (MTU).
- Average number of hours that the system functions before not supplying certain consumers for the first time (MTTF).
- Probability of no longer supplying power to certain consumers (availability).
- Average number of failures per hour during a year ( $\lambda_e$ ).
- Average repair time ( $1/\mu_e$ ).
- Optimal frequency of preventive, predictive maintenance.
- Optimal replacement parts storage.

According to the required criteria and system configuration, there are three main modeling techniques that could be used to perform a reliability analysis.

#### 1) Fault tree diagram – combination technique

This technique is based on the combination of single unexpected events to perform the study. A fault tree diagram breaks down an unexpected event into single events. The immediate causes of a loss of electrical supply are defined as first order cut-sets. The causes of these intermediary events are defined as second order cut-sets, and so on until the last level of cause-effect event combination.

The analytical resolution of complex or large systems with reconfiguration possibilities and complex maintenance strategies is beyond the possibilities of this technique and the results should be less accurate.

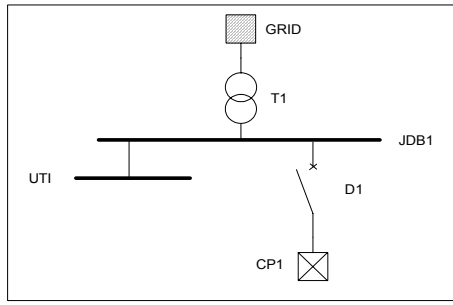


Figure 2. Single line and related fault tree diagrams

## 2) Markovian graph – combination and sequential technique

The combination and sequential techniques combines the occurrence of single events whilst taking into account the moment in time when the events occur.

The Markovian technique is commonly represented by a graph that shows the various possible states in the system. Every link between states are quantified by rates, which can be failure rates, repair rates or representative operating modes frequencies. The rates (assumed constant) represent the probability for the system to change the actual status.

## 3) Pétri network – combination and sequential technique

Petri network is the more complex combination and sequential technique. The network is represented by places, transitions and tokens. The crossing of a transition via a token corresponds to a possible functional or malfunctional system event. This transitions can be associated with any type of probability law, so simulation is the only way to enable calculations to be resolved.

The modeling of a system using a Petri network is the most closest representation to the real operation of the system being studied. In spite of that, the requirement to simulate the calculations limits the use of this technique.

Proceeding with the methodology described enables the assessment to be made of the system's performance level and thus determine the configuration of the network architecture, components retrofit, preventive and predictive maintenance strategy that meets dependability criteria without forgetting economic constraints.

$\lambda_a$ : frequency at which there is loss power supply  
 $\lambda_b$ : frequency of GE failure  
 $\mu$ : frequency of repair

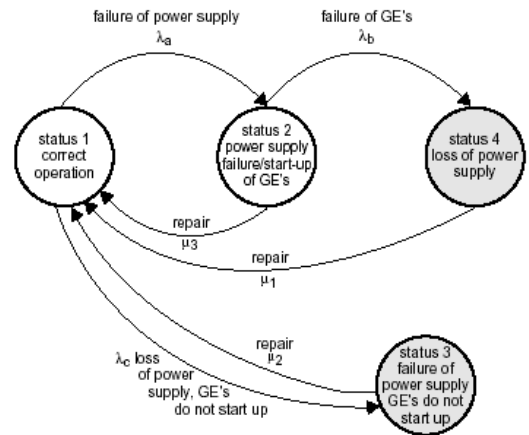


Figure 3. Example of a Markovian graph

## F. Reliability Index

As it was mentioned before, modelling enables quantitative analysis calculating dependability criteria. With this results it could be determined the component or installation unavailability. That is the ratio of time per year in which a specific component of a system, or a system itself, is not available.

This ratio allows calculating a reliability index defined with the following equation:

$$RI = \frac{(AT - UT)}{TT} = \frac{(AT - UT)}{(AT + UT)} \quad (5)$$

Where "AT is available time", "UT is unavailable time", and "TT is total operating time", all of them in hours per year. When the reliability index equals one, then the installation is absolutely (theoretical) immune to power losses.

#### IV. TOTAL RELIABLE EFFICIENCY

Energy efficiency analysis focus only on energy savings and performance, but generally the studies assume that there is no interruption on energy supply. That implies that the energy consumption (losses) during breakdown and recovery procedures (mostly related to continuous production processes) is not taken into account and normally this inefficiency is very representative.

The priority for energy efficiency project and strategies is established around possible savings and capital investment required.

On the other hand, reliability studies focus on the criticality level of the distribution network and the availability of the energy supply, but in no case consider the inefficiencies related to oversized equipment, or components not included in the network. The priority for projects or strategies is established upon the costs related to unavailability.

Total Reliable Efficiency (TRE) follows a simple methodology that involves energy consumption evaluation, basic process analysis and energy risk quantification, to obtain a ranking of efficiency and risk reduction measures. Measures that enables to quantify and prioritize options and generate multiyear action plans and strategies that focus in one or in both point of views.

##### A. Basic methodology

The first phase of a TRE study begins with a global preliminary analysis that determines the functional and behavioural relations between consumers (components) and energy, and components and distribution network.

The main goal of this reliable efficiency diagnostic is to identify the right detailed analysis required for every part of the system (efficiency, reliability or both), and configure so a comprehensive analysis working plan.

The second phase is to carry on in parallel the detailed analysis according to the plan, energy audits and modeling.

The results of the second phase are rearranged and for every area or component of the analyzed system, the efficiency index and reliability index is calculated. According to the range of index values a priority must be established, so every component will have a level of efficiency and a level of reliability.

The third phase starts once this priority levels are determined. Depending of the level reached in both indexes, the improvement projects and maintenance strategies will follow one or both points of view. For example, a poor efficiency level and a high reliability level implies that this component should follow an improvement plan related to energy efficiency. On the other hand, a poor efficiency and reliability level requires to focus on both approaches, but in this specific case, with a priority for reliability. Without energy supply there is no need for efficiency solutions.

##### B. Continuous improvement management

Whatever improvement plan is defined, the important thing is to converge on the appropriate and required solution and strategy for every system without losing the perspective, and without losing the two points of view that are complementary even though there are big differences between the two approaches.

1) *Optimization projects – technological change:* The optimization projects must consider the particularities of the system's requirements for efficiency and reliability to develop an integral solution.

2) *Reliable efficiency maintenance:* The maintenance policy and strategy based on the results of TRE must also consider if the component or system requires a efficiency or reliability centered maintenance. In the last case a disaster recovering plan (DRP) should be appointed to act in case of an unexpected event.

3) *Monitoring and targeting:* once the system is optimized by implementing the projects and strategies, it must be monitored to observe any deviation, on whatever representative parameter or value that could predict a possible malfunction or inefficiency. An energy management system capable to measure power quality and consumption parameters is essential to manage the continuous improvement of the installations.

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