ENGINSOFT

WHITE PAPER

Tolerance analysis on Emax 2 low voltage air circuit-breakers series

ABB SACE company profile

ABB (www.abb.com) is a leader in power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact. The ABB Group of companies operates in around 100 countries and employs about 150,000 people.
Technology leadership, global presence, application knowledge and local expertise are key factors in order to offer products, systems and services that enable, ABB's customers, to improve their business in terms of energy efficiency, reliability of networks and industrial productivity.

ABB was born in 1988 from the merge of two leading European industrial Companies: the Swedish ASEA, founded in 1883, and the Swiss Brown Boveri, founded in 1891, which acquired the oldest electromechanical Italian company in 1903, Tecnomasio Italiano, founded in 1863. In Italy ABB gathered the legacy and the experience of most of the electromechanical Italian sector and of important companies who have contributed to the industrial history of the Country such as Ercole Marelli, SACE, Officine Adda and Ansaldo Trasformatori.

ABB is organized in five divisions called Power Products, Power Systems, Discrete Automation and Motion, Low Voltage Products and Process Automation and in eight regions: North America, South America, Northern Europe, Central Europe, Mediterranean, India, Middle East & Africa (IMA), North Asia, South Asia. In every region there is a regional hub.

ABB in Italy

ABB Italy (www.abb.it) has worldwide technological leadership for low voltage moulded case and air circuit breakers, low voltage residual current devices, pressure sensors and transmitters, medium voltage air insulated switchgears and medium voltage breakers. Moreover ABB Italy has worldwide responsibility of R&D for automation systems products in power generation systems, of development, production and sales of MV asyncronous motors (explosive atmosphere, slip ring and large induction motors) and of the Global Technical Service Center for motors and generators. It is a center of excellence for turn-key plants in the oil and gas field and for advanced automation solutions. ABB Italy invests 2,3% of revenues in R&D.

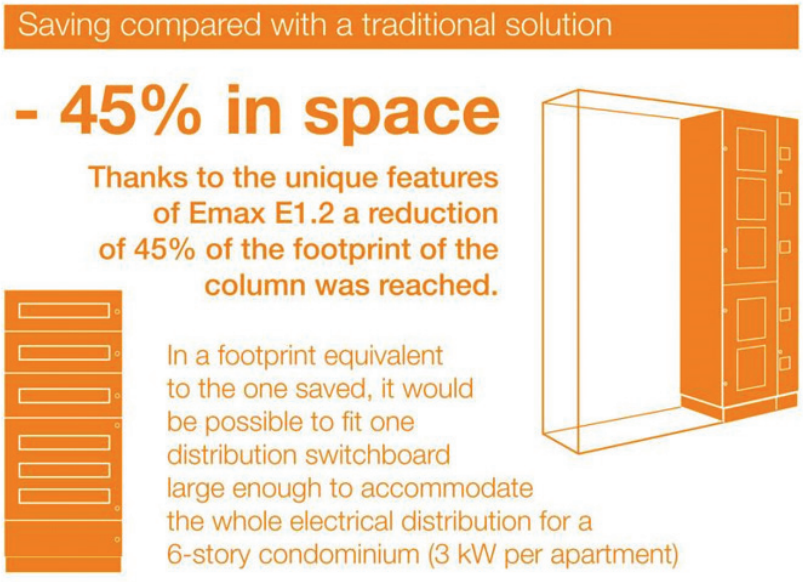
The principles of the business of ABB Italy

To build value, leadership and performance in ABB, responsibility, respect and determination are crucial. Take responsibility and act with respect and determination is the way to ensure the development of ABB's traditional points of strength: technology leadership, pioneering spirit and ability to be at home in any market.

The key to success lies in the ability of ABB's people to understand and apply the business principles, collected in a Code of Conduct, which demonstrates the commitment to act in an ethical manner with integrity and respect in every situation, while respecting the rights of persons as individuals

Sustainable development

Our commitment to sustainable development comes from a clear strategic planning that enables us to deliver today, answers to customers seeking products and services with



high energy efficiency and environmental performance. The attention to environmental issues and the focus on resource saving, allowed us, over the past two years, also to significantly increase our efficiency. In our business, we aim to reach excellence in management systems covering quality, environment, safety and ethics. We want to give to all employees a safe working environment where people feel gratified and meet society's expectations on corporate social responsibility.

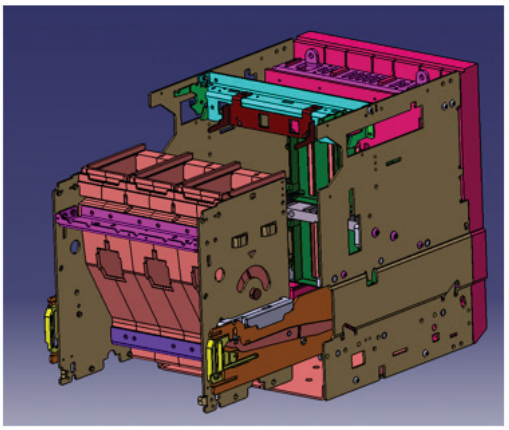
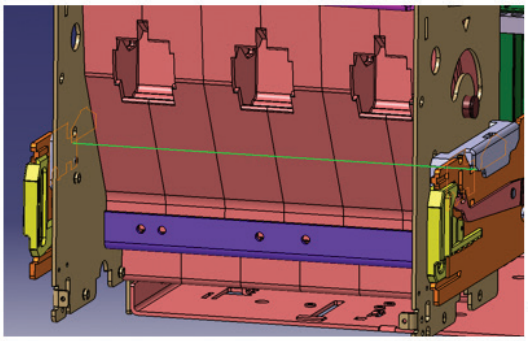


Figure 1 – Different versions of the Emax 2 product family



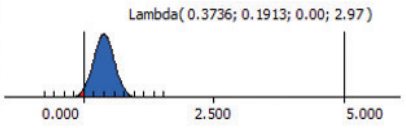


Figure 2 – Initial statistical distribution of the gap between joined guide-plates

Product description

The power needed, when needed

SACE Emax 2 is a new series of low voltage air circuit-breakers available up to 6300 A and with the ability to efficiently and simply control electrical installations – from the traditional to the more complex – with minimum impact, the new SACE Emax 2 circuit-breakers represent the evolution of a circuit-breaker into a Power Manager.

SACE Emax 2 have been designed to increase efficiency in all installations: from industrial and naval applications to traditional and renewable power generation installations, buildings, data centers and shopping centers. Reliable protection and systems managed with competence.

Power Controller

The exclusive Power Controller function available on the new SACE Emax 2 circuit-breakers monitors the power managed by the circuit-breaker, keeping it below the limit set by the user. As a result of this more effective use, the peak of power consumed can be limited allowing savings on electricity bills.

The Power Controller, patented by ABB, disconnects non-priority utilities, such as for example electric car charging stations, during the times when consumption limits need to be respected, and connects them again as soon as it is appropriate. When required, it automatically activates auxiliary power supplies such as generator sets. No monitoring system is required: it is sufficient to set the required load limit on Emax 2, which can control any circuit-breaker located downstream, even if it is not equipped with a measurement function. In installations that are already equipped with energy management systems, the load limit can also be modified remotely.

Ekip Touch

SACE Emax 2 circuit-breakers are equipped with a new generation of protection trip units that are easy to programme and read. The Ekip Touch trip units measure power and energy with precision and save the most recent alarms, events and measurements in order to prevent faults to the installation or trip effectively when necessary.

Network Analyzer

Upon request, the Network Analyzer function is also available, which controls the quality of absorbed power in real time and with extreme precision.

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parteMobile;1 / traversaInferiore;1 / larghezza / Size	270.00 +0.00 -0.50	16.27%
parteMobile;1 / scatola4;1 / plane5 / to plane4	45.00 +0.00 -0.20	12.11%
parteMobile;1 / scatola6;1 / plane7 / to plane6	45.00 +0.00 -0.20	12.11%

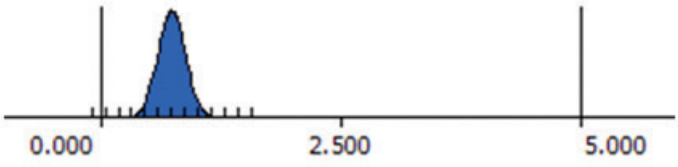

Figure 3 – Quantitative impact of variables on the result and its final statistical distribution

In addition, the innovative Ekip Touch and Hi Touch trip units in the G version include all the functions of generator protection switchgear, offering a safe control solution that is ready to use.
No external devices, wiring and inspections are required.

Integration is easy. Even from afar

SACE Emax 2 series circuit-breakers have been designed to be integrated directly into all types of switchgear and automation and energy management systems to improve productivity and energy consumption. Complete integration into smart grids, in buildings and industrial plants is possible.
All circuit-breakers can be equipped with communication units for use with Modbus, Profibus and Devicenet protocols and with the modern Modbus TCP, Profinet and Ethernet IP protocols, which can be installed directly on the terminal box at any time.
The integrated IEC61850 communication module enables connection to automation systems and intelligent networks (Smart Grids). Accurate measurements of current, voltage, power and energy are all available by means of the communication modules and allow the trip units to be used as multimeters.
All circuit-breaker functions are also accessible via the Internet, in complete safety, through the Ekip Link switchgear supervision system and the Ekip Control Panel operator panel. The power and auxiliary connections are optimized to simplify connection to the switchgear.
The power terminals, which can be oriented horizontally or vertically, have been designed for the most common busbars, while the push-in connections of the auxiliaries ensure immediate and safe wiring.

CASE STUDY: New Ferryboat Emax 2 for the highest efficiency in panelbuilding

The customer

I.M.E.S.A. (based in Jesi, near Ancona - Italy) is a company that has been operating since 1972 in the field of electromechanical constructions.
IMESA is one of the leaders in Europe in the production of Low Voltage and Medium Voltage switchboards, SF6- insulated switch-disconnectors for internal and external installations for MV, supervision and control systems as well as turnkey electrical systems.

CETOL 6σ and Tolerance Analysis

EnginSoft is European distributor of leading Precise Constraint Technology software CETOL 6σ, developed by Sigmetrix LLC.
CETOL 6σ is a tolerance analysis and optimzation software tool providing the invaluable insight needed to address the above issues and to confidently release designs for manufacture. You will be able to assess the manufacturability of your designs long before they reach production.
CETOL 6σ enables designers and engineers to address multi-dimensional problems, by using a mathematical description of your CAD geometry. This unique method allows you to receive immediate analytical feedback, utilising the easy-to-use modelling, analysis and reporting components. The user is guided through the tolerance analysis and optimization process whilst being informed about missing or erroneous data.
Unlike simple 1D stack-up analysis or Monte Carlo Simulation, CETOL 6σ pursues a statistical approach employing advanced precise constraint technology, displayed in an intuitive graphical user interface. This approach accelerates the ability to identify part sensitivities and components that have the most significant contribute to the total variation. Discovering critical-to-quality assembly characteristics has never been easier.
For more information:
http://www.tolerance-analysis.co.uk/products/cetol-60

The challenge

In the context of a diesel-electric state-of-the-art ferryboat, I.M.E.S.A. faced the challenge of creating a switchgear column – feeding main distribution and motors- able to:

- Be fully selective with downstream circuit-breakers (Tmax T4)
- Grant a service short-circuit breaking capacity of 50 kA @ 600V AC
- Have a horizontal bussing distribution system
- Realize the most compact solution compatible with the use of withdrawable circuit-breakers.

These requirements originate by the need for extremely compact switchgear, a typical requirement that can arise from a marine environment.

The ABB solution

These requirements are really challenging. The first and second requirements clearly call for a category B circuit-breaker, while the third and the fourth are apter for a moulded-case circuit-breaker (able to be mounted in horizontal position, compact in dimension).

No product other than ABB Emax E1.2 in the world of the Low Voltage Breakers could entirely fulfil the above requirements. ABB Emax 1.2, the most compact size of the Emax 2 range of ACBs, is an innovative product, able to break up to 66 kA @ 440V AC (or 50 kA @ 690V AC) and to withstand 50 kA for one second.

Thanks to these unique features, IMESA was able to realize a high-efficiency switchboard, with five Emax E1.2 fitted in one column. The E1.2 chosen for this project are equipped with the new Ekip Touch trip units (LSI version).

General description of the working methodology

Emax 2 is a complex product made up by hundreds of single parts assembled together that has several measurement requirements to satisfy. These requirements deal with assemblability, product quality and security and all of them refer to geometric quantities (i.e. the distance between two parallel planes and their relative orientation).

The measurement requirements depend on how the single parts are located and oriented with respect to the others: these information are provided by the contact conditions between adjacent parts and the geometric relations between features belonging to each single part. The complex three dimensional vectorial chain is based on the translation of the previous information into the numerical model. The definition of the output measures (requirements) close the tolerance chain.

If all parts were perfect (nominal shape) the chain would be univocally determined and could be solved by using any CAD tool. In reality both contact conditions and geometric features aren't the ideal ones, because real geometric entities exhibit a certain dispersion with respect to the nominal value due to the imperfections inherent in manufacturing processes. As a consequence, the assembly outputs are no longer univocally determinable and outputs become dispersed as well.

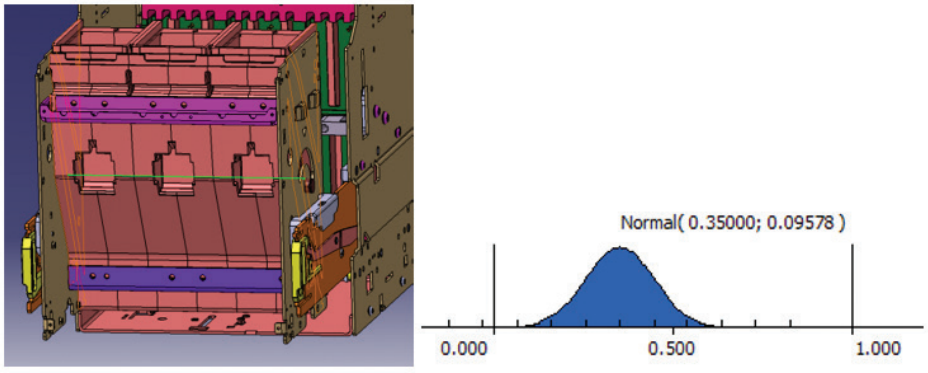

Figure 4 – Initial statistical distribution of the gap between frame and boxes

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parteMobile;1 / fiancata_SX;1 / spessore / Size	3.00 ±0.25	18.97%
parteMobile;1 / fiancata_DX;1 / spessore / Size	3.00 ±0.25	18.97%
leftShoulderAssembly;1 / LEFT_GUIDE_ASSEMBLY;1 to leftLowerFixedGuide;1.1 / TY	Joint Mobility	12.36%

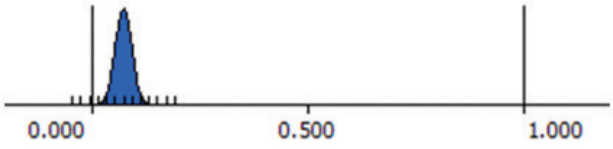


Figure 5 – Quantitative impact of variables on the result and its final statistical distribution

Designers control and limit the variability of the measure requirements (trying to keep them between the acceptance limits) by assigning proper dimensional and geometrical tolerances to the components: these tolerances should reflect the way parts are produced (manufacturing process), assembled (assembly sequence) and the way dimensions are measured (quality controls).
The investigation of how tolerances affect the dispersion of the functioning measurements is carried out through a statistical approach.

Model development and targets

Aim of the analysis performed by EnginSoft was the validation of the Emax 2 project. Validation means checking that product requirements are within their area of acceptability. Such a need is due to the fact that the propagation of the tolerances in assembled products doesn't guarantee compliance with these requirements even when all parts composing the assembly were produced respecting the tolerances assigned to them by the designer.

Among others, three requirements of particular relevance have been identified for this product:
Requirement on the capability of the single parts to be assembled together (assemblability),
Requirement on the product quality
Requirement on security.
The procedure requires translating the above requirements in geometric entities in the CAD model, defining a range or threshold of acceptability for them and the assessment of their variability defined by the design (i.e. tolerances associated with nominal values).

The variability of functional measures is quantified after the analysis. The statistical analysis provides quantitative information on which take the most appropriate corrective actions and with minor impact on costs to improve the robustness of design.

The entire procedure of construction of the model, its resolution, results visualization, their interpretation and appropriate corrective actions are handled by Cetol 6σ, a dedicated software developed by the Sigmetrix. Cetol 6σ automates the whole procedure following a standardized logical path remaining within the design environment, since it is fully embedded in the most popular CAD softwares.

Several practical advantages can be achieved: reduction of redesign cycles, prediction and reduction of the number of rejects, reduced reworks, fewer prototypes/samplings, dimensional control focused on the measures with major influence on product requirements, reduced "time to market".

Obtained results and smart corrective actions

Assemblability requirement

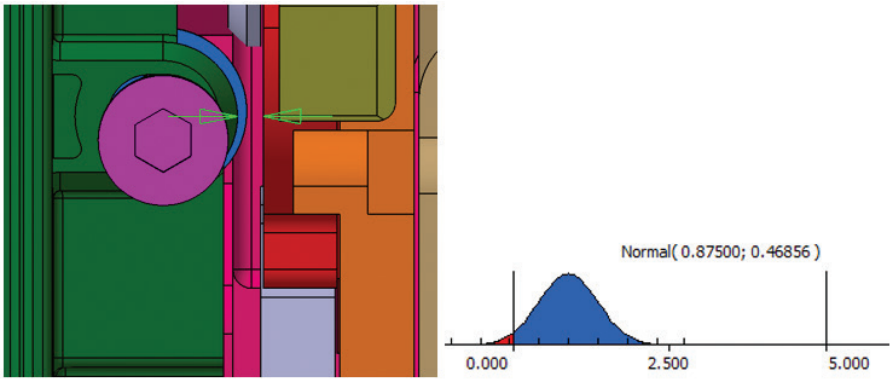
The aim of the analysis is the prevision of potential issues during the installation of the movable part with respect to the fixed one. The assessment of this requirement is based on the overall dimensions of the two mating parts and their difference.

The result obtained using the design specifications highlights a low probability (Fig. 2, approximately 3 products every 100) to get a negative gap between the supports and the guides of the movable part: this results in possible interferences and thus non-compliances during assembly phases.
The sensitivity analysis is a powerful tool that allows the identification of the dimensions and tolerances that, within the dimensional chain, have the greatest influence on the mean value and the width (standard deviation) of the resulting statistical distribution. The variables with the highest influence on the functional measure were found to be the tolerances associated with the thickness of the guide plates. They directly affect the width of the statistical distribution representing the gap in the mating.

The reduction of only two tolerances among the thousand in the model has allowed the vanishing of the non-compliances.

Product quality requirement

The aim of the analysis is the quantitative assessment of the gap between the plastic boxes held together and the frame of the movable part. During the life of a circuit breaker stressful condition can be encountered, i.e. high short circuit current passing through the breaker, when this happen the position of the phases relative to each other and to the main structure is crucial to the performance. We must ensure a perfect fit in order to maximize results and reduce risks.



Fiure 6 – Initial statistical distribution of the distance between the shutters and the external wall

Name:	Value:	Contribution: (>= 1%)
piastraTripolare;1 / ID1_@upperCrossBeam / to hor	201.00 ±0.50	33.01%
piastraTripolare;1 / ID2_@upperCrossBeam / to hor	201.00 ±0.50	33.01%
rightShoulderAssembly;1 / RIGHT_GUIDE_ASSEMBLY;1 to rightLowerFixedGuide;1.1 / TY	Joint Mobility	7.51%

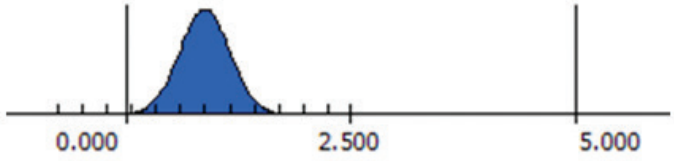


Figure 7 – Quantitative impact of variables on the result and its final statistical distribution

The result obtained using the design specifications highlights a high width for the output statistical distribution with respect to the ideal condition of operation, i.e. a mean value of zero for the gap and a null width of the distribution around the mean value.

Now, the targets to achieve are: shift the mean value of the distribution towards lower values and reduce its width. As previously happened, tolerance analysis has allowed the identification of the variables with the greatest influence on the final requirement: results from sensitivity analysis have provided all the necessary information to act in a targeted manner. The tolerances belonging to the width of each box have the major influence on the dispersion of the gap value around the nominal, as a consequence it is on these that it was decided to take action.
The study has increased the robustness of the design through the reduction of only two tolerances (among thousands in the model) along with the change of a nominal value.

Security requirement

The aim of the analysis is the detection of possible risks of locking of the shutters during the extraction of the movable part. The closure of the shutters must always be ensured to avoid contact between the maintenance engineers and the parts under voltage of the switch.

The results obtained using the design specifications shows a potential number of non-compliance of approximately 5%. For these components the external wall of the shutters is in contact with the sliding guides causing friction and the subsequent locking.

The sensitivity analysis has identified the tolerances associated with the placement of two holes as the variables of greatest influence on the dispersion of the gap around the mean value.

The previous information could be used to undertake the appropriate corrective actions when products and parts are only on the drawings, avoiding their discovery during the prototyping phase and the costs associated with the production, quality controls and reworks. The reduction of only two tolerances among the thousands in the model allowed the avoidance of the non-compliances for the requirement under investigation.

Conclusions

The activity performed in collaboration with EnginSoft has allowed ABB to meet all the design requirements for the product under investigation. Through the analysis of the propagation of the tolerances within the dimensional chain it has been possible to identify the dimensions and tolerances with the major impact on the functional measurements and therefore to act in a targeted way for the resolution of potential non-compliances, avoiding the generalization of their treatment. The resulting benefits are multiple, meeting objectives: reduction of the redesign cycles, savings on scraps and reworks, reduced number of prototypes, reduced “time to market”.

Giulio Tribulato - ABB SACE
Enrico Boesso - EnginSoft

EnginSoft is a premier consulting firm in the field of Simulation Based Engineering Science (SBES) with a global presence. It was founded in 1984, but its founder and initial employees had been working in SBES since the mid '70s. Throughout its long history it has been at the forefront of technological innovation and remains a catalyst for change in the way SBES and CAE technologies in general are applied to solve even the most complex industrial problems with a high degree of reliability.

Today, EnginSoft is comprised of groups of highly qualified engineers, with expertise in a variety of engineering simulation technologies including FEM Analysis and CFD, working in synergic companies across the globe. We are present in Italy, France, Germany, the UK, Turkey and the U.S.A. and have a close partnership with synergetic companies located in Greece, Spain, Israel, Portugal, Brazil, Japan and the U.S.A.

EnginSoft works across a broad range of industries that include the automotive, aerospace, defense, energy, civil engineering, consumer goods and biomechanics industries to help them get the most out of existing engineering simulation technologies.

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