Design Report

LOT 2: Distribution and Power Transformers

400kVA, 1000kVA and 2000kVA Oil-Immersed Transformers

An assessment of the relationship between energy-efficiency and price

Prepared for:

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DISCLAIMER

ACKNOWLEDGEMENTS

The transformer designs presented in this report were prepared through a joint working relationship established by CLASP's Europe office between Eoin Carey, with over 20 years design experience in oil-immersed transformer design at the recently closed ABB plant in Waterford, Ireland, and Paul Goethe and Nahid Pempin of Optimized Program Service (OPS) in Cleveland, Ohio. OPS used their design software to prepare three-phase 50Hz oil-immersed designs, which were then sent to Eoin Carey for review and comment. Through this iterative process the set of transformer designs presented in this report were developed, representing a range of efficiency values for the European market. Michael Scholand of Navigant Consulting Europe assisted CLASP in this undertaking, including liaising with Eoin Carey and OPS, and preparing this report on the results.

COMMENTS

Stakeholders are invited to provide comment to CLASP on the designs presented and the cost-breakdowns shown in this report. This report relies primarily on the material cost inputs published in the July 2010 draft VITO Preparatory Study, Chapter 2, Table 2-21 "Overview of material prices for liquid immersed and dry-type transformers in €/kg". These material prices are based on the US Department of Energy (published September 2007) with supplemental input from European stakeholders in August and September of 2009. There are, however, some other cost assumptions and estimates, including a labour and manufacturer mark-ups which have been added to build up to a final manufacturer's selling price. Please submit any comments on this report to:

Anita Eide, Director of European Programmes, CLASP on AEide@clasponline.org

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Acronyms and Abbreviations

BOM	Bill of Materials
°C	degrees Celsius
CLASP	Collaborative Labeling and Appliance Standards Program
DER	Distributed Energy Resources
DG	Distributed Gap (i.e., a type of wound core)
EC	European Commission
EN	European Standard (Européenne Norme)
EU	European Union
HO	Laser-scribed domain refined silicon steel
kV	kilovolt (i.e., thousand volts)
kVA	kilovolt-Ampere
M_	Grain-oriented silicon steel, M6, M4, M3, M2 (see section 2.2)
OPS	Optimized Program Service
R&D	Research and Development
SA1	Amorphous core material
US	United States
W	Watts

1 Summary of Findings

In support of the European Commission's analysis of Transmission and Distribution Transformers, CLASP undertook a study of the relationship between manufacturer's selling price and efficiency for three of the seven base case transformers being evaluated by the Commission. The three transformers studied are:

- 400 kVA oil-immersed three-phase unit, representing distribution transformers
- 1000 kVA oil-immersed three-phase unit, representing industry transformers
- 2000 kVA oil-immersed three-phase unit, representing distributed energy resources (DER) transformers

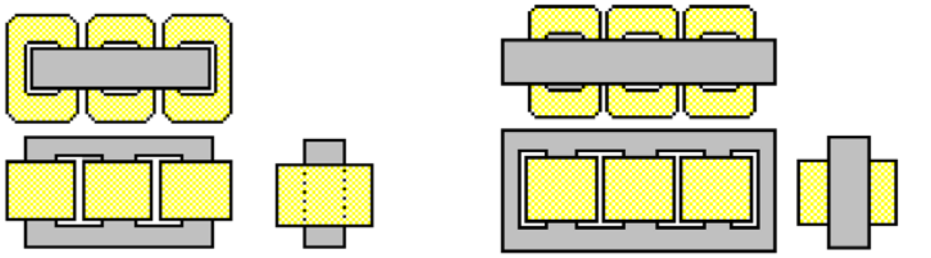
Understanding how the price of transformers increases as the efficiency improves is important because it enables an accurate assessment of life-cycle costs and associated payback periods. Generally, a transformer becomes more expensive as efficiency improves because it is incorporating either more material and/or better quality materials.

CLASP prepared designs in accordance with the manufacturer's questionnaire issued by VITO with the revised Chapters 1 through 5 of the Preparatory Study in July 2010. The table below presents the designs that were created, a baseline unit ("Eff0"), followed by designs with lower losses on core and coil, as specified in VITO's questionnaire. There were eleven 400 kVA, eleven 1000 kVA and six 2000 kVA designs created in this analysis – in total, 28 transformer designs. In each case, both stacked core and wound core designs were prepared. The stacked cores use grain-oriented electrical steel and the wound core designs use amorphous material.

Table 1-1. Table of Oil-Immersed Transformer Designs Prepared

400 kVA		1000 kVA		2000 kVA	
Stacked Core	**Wound Core**	**Stacked Core**	**Wound Core**	**Stacked Core**	**Wound Core**
Eff0 Eff1 Eff2 Eff3 Eff4 Eff5 Eff6	Eff7 Eff8 Eff9 Eff10	Eff0 Eff1 Eff2 Eff3 Eff4 Eff5 Eff6	Eff7 Eff8 Eff9 Eff10	Eff0 Eff1 Eff2	Eff3 Eff4 Eff5

The figure below illustrates the stacked and wound core-coil assembly used in these three-phase transformer designs. Stacked cores were designed as three-legged mitred cores and wound cores were designed using amorphous material in a five-legged wound core.



(a) Three-legged three phase core (b) Five-legged three phase core

Figure 1-1. Core Construction Used for (a) Stacked and (b) Wound Cores

Designs were prepared taking into account the maximum losses and target impedance contained in EN 50464-1 and EN 50541. A summary of the design results are presented in the following subsections for each of the three transformers. Subsequent chapters of this report describe the methodology followed, the inputs used and more detail on the results. There are six transformer designs included in the Annexes to this report, one stacked and one wound core design from each of the three transformers.

1.1 Results for 400 kVA

The 400 kVA three-phase oil-immersed transformers were designed to operate on a 50Hz system with a primary voltage of 11kV and a secondary voltage of 400V. The transformer has a design temperature rise of 65°C, a Lo-Hi winding configuration, and a tap configuration of four 2½ percent taps—two above and two below the nominal voltage. The figure below presents the results of CLASP's analysis along with the designs that were published in the draft Preparatory Study (labelled as "VITO" in the graphic). The amorphous designs have been given a different shaped symbol to more easily identify them.

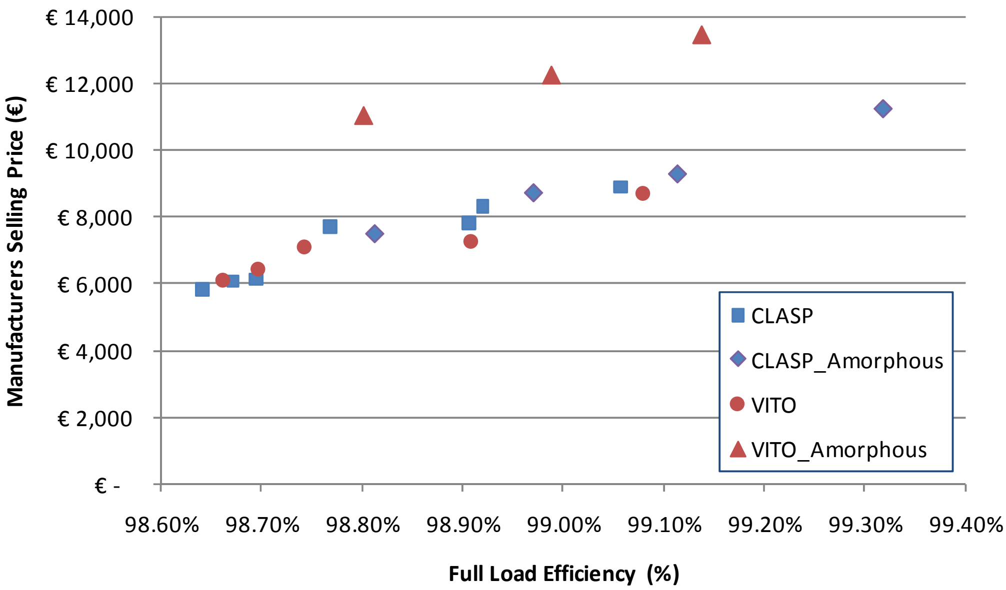


Figure 1-2. Price vs. Efficiency of VITO and CLASP 400 kVA Oil-Immersed Transformers

The designs published by VITO using conventional electrical steel appear to be in line with the manufacturing cost estimates prepared from the 400 kVA transformer designs commissioned by CLASP. The amorphous material designs published by VITO however appear to be over-priced, and not in alignment with CLASP's designs, which are based on a prefabricated core.

The table below presents tabular results and the corresponding relative manufacturer's sales prices for the designs under consideration for the 400 kVA transformer. This indexed table of price increases was issued by VITO in their request that manufacturers provide an indication of the relationship between price and efficiency.

Table 1-2. Indexed Price Increases Relative to Baseline for CLASP's Designs, 400 kVA

BC1 – Distribution Transformer 400 kVA		E0	D0	C0	B0	A0	Amorph.
		930 W	750 W	610 W	520 W	430 W	205 W
Dk	6000 W						
Ck	4600 W		100%	104%	106%	132%	129%
Bk	3850 W				143%	134%	150%
Ak	3250 W					153%	160%
Best Tech.	2500 W						193%

In addition, CLASP prepared a "best technology" design for this unit which holds core losses at 205W and reduces the winding losses to 2500W. This particular best technology design represents an indexed price of a 193%, or approximately double the cost of the baseline D0Ck unit.

The table below compares the CLASP and VITO transformer designs on a price basis and calculates the difference in price. In general, the conventional electrical steel designs are similar in price, however the amorphous designs prepared by CLASP are approximately 30% less expensive than those published in the Preparatory Study.

Table 1-3. Price Comparison of 400 kVA Transformer Designs

Design Losses		CLASP Designs		VITO Designs		Difference of CLASP Relative to VITO
Core (P0)	Coil (Pk)	Efficiency	Price	Efficiency	Price	
750	4600	98.64%	€ 5,825	98.66%	€ 6,122	-4.9%
610	4600	98.67%	€ 6,079	98.70%	€ 6,428	-5.4%
520	4600	98.70%	€ 6,146			
520	3850	98.92%	€ 8,312	98.91%	€ 7,285	14.1%
430	4600	98.77%	€ 7,711	98.74%	€ 7,102	8.6%
430	3850	98.91%	€ 7,821			
430	3250	99.06%	€ 8,891	99.08%	€ 8,693	2.3%
205*	4600	98.81%	€ 7,516	98.80%	€ 11,019	-31.8%
205*	3850	98.97%	€ 8,740	98.99%	€ 12,244	-28.6%
205*	3250	99.11%	€ 9,304	99.14%	€ 13,468	-30.9%
205*	2500	99.32%	€ 11,252			

* Amorphous core transformer designs.

Improving efficiency from the base case model of D0Ck (750W, 4600W) up to A0Ak (430W, 3250W) has an average cost per one-hundredth percent improvement in efficiency of €88 for the CLASP designs and €80 for the VITO designs. In other words, the slopes that define the relationship between the manufacturer selling price and efficiency are the same. However, the average cost per one-hundredth percent improvement in efficiency for the amorphous designs is €85 for the CLASP designs and €232 for the VITO designs.

1.2 Results for 1000 kVA

The 1000 kVA three-phase oil-immersed transformers were designed to operate on a 50Hz system with a primary voltage of 11kV and a secondary voltage of 400V. The transformer has a design temperature rise of 65°C, a Lo-Hi winding configuration, and a tap configuration of four 2½ percent taps—two above and two below the nominal voltage.

The figure below presents the results of CLASP's analysis along with the designs that were published in the draft Preparatory Study (labelled as "VITO" in the graphic). The amorphous designs prepared by CLASP have been given a different shaped symbol to more easily identify them. VITO did not publish any amorphous designs for the 1000 kVA unit.

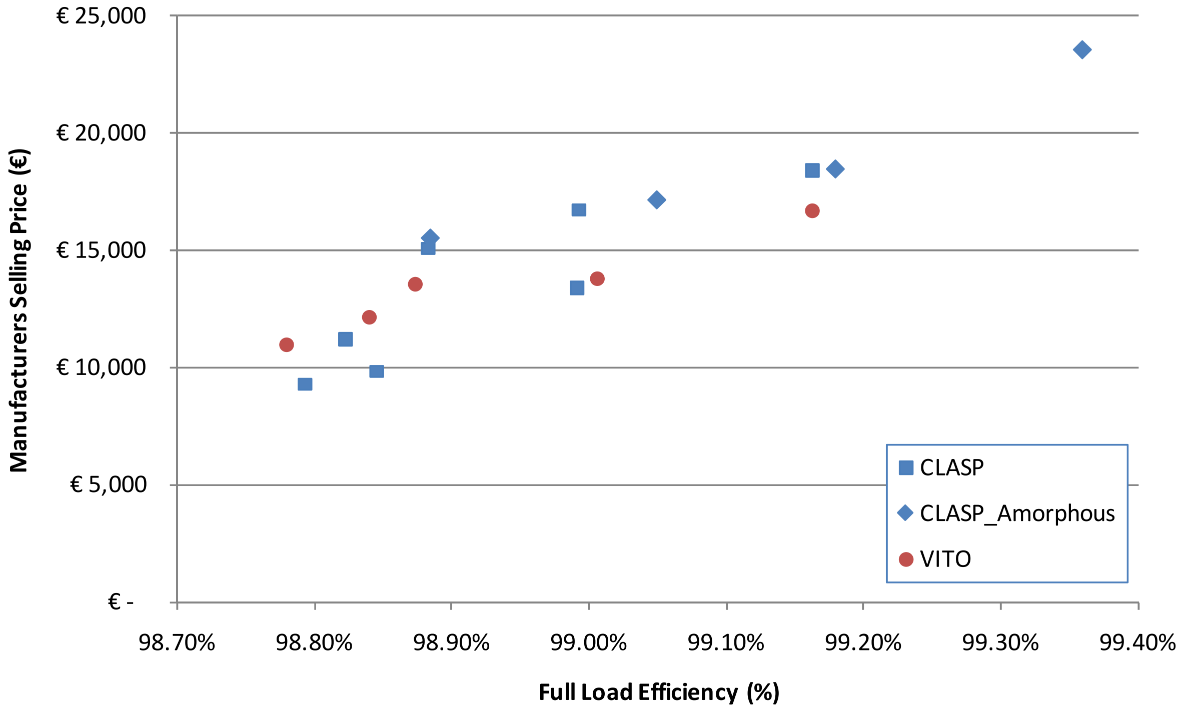


Figure 1-3. Price vs. Efficiency of VITO and CLASP 1000 kVA Oil-Immersed Transformers

The designs published by VITO using conventional electrical steel appear to be in line with the manufacturing cost estimates prepared from the 1000 kVA transformer designs commissioned by CLASP.

The table below presents tabular results and the corresponding relative costs for the designs under consideration for the 1000 kVA transformer.

Table 1-4. Indexed Price Increases Relative to Baseline for CLASP's Designs, 1000 kVA

BC2 – Industry Transformer 1000 kVA		E0	D0	C0	B0	A0	Amorph.
		1700 W	1400 W	1100 W	940 W	770 W	400 W
Dk	13 000 W						
Ck	10 500 W	100%		106%	121%	163%	168%
Bk	9000 W				145%	180%	185%
Ak	7600 W					198%	199%
Best Tech	6000 W						254%

In addition, CLASP prepared a "best technology" design for this unit which holds core losses at 400W and reduces the winding losses to 6000W. This particular best technology design represents an indexed price of a 254%, or more than double the cost of the baseline E0Ck unit but with significantly lower winding losses.

The table below compares the transformer designs prepared on a cost basis and looks at the difference. On average, the CLASP transformers are approximately 3% less expensive than those published in the draft Preparatory Study. Again, these data demonstrate that there is a good price-efficiency correlation between the CLASP and VITO designs that use grain-oriented electrical steels.

Table 1-5. Price Comparison of 1000 kVA Transformer Designs

Design Losses		CLASP Designs		VITO Designs		Difference of CLASP Relative to VITO
Core (P0)	Coil (Pk)	Efficiency	Price	Efficiency	Price	
1700	10 500	98.79%	€ 9,270	98.78%	€ 10,926	-15.2%
1100	10 500	98.85%	€ 9,827	98.84%	€ 12,128	-19.0%
940	10 500	98.82%	€ 11,177			
940	9000	98.99%	€ 13,396	99.01%	€ 13,767	-2.7%
770	10 500	98.88%	€ 15,066	98.87%	€ 13,548	11.2%
770	9000	98.99%	€ 16,716			
770	7600	99.16%	€ 18,398	99.16%	€ 16,717	10.1%
400*	10 500	98.88%	€ 15,538			
400*	9000	99.05%	€ 17,166			
400*	7600	99.18%	€ 18,484			
400*	6000	99.36%	€ 23,570			

* Amorphous core transformer designs.

Improving efficiency from the base case model of E0Ck (1700W, 10,500W) up to A0Ak (770W, 7600W) has an average incremental cost per one-hundredth percent improvement in efficiency of €371 for the CLASP designs and €190 for the VITO designs. Although it would appear that the cost of improving efficiency for the CLASP designs is higher, the primary reason for this is due to the fact that CLASP's base case transformer design is approximately €1,500 less expensive than the VITO design. If the CLASP price is set to be the same as that of the draft Preparatory Study, the average incremental cost per one-hundredth percent improvement in efficiency drops to €150 for the CLASP designs – lower than, but more aligned with, the VITO designs.

It is also interesting to note that although VITO doesn't have any amorphous designs, the CLASP data show that the slope of the relationship between price and efficiency is reasonably constant over the efficiency values covered by amorphous material. The average incremental cost per one-hundredth percent improvement in efficiency is €372, just slightly higher than CLASP's estimate of the increment for grain-oriented electrical steels at €371.

1.3 Results for 2000 kVA

The 2000 kVA three-phase oil-immersed transformers were designed to operate on a 50Hz system with a primary voltage of 24kV and a secondary voltage of 690V. The transformer has a design temperature rise of 65°C, a Lo-Hi winding configuration, and a tap configuration of four 2½ percent taps—two above and two below the nominal voltage.

The figure below presents the results of CLASP's analysis along with the designs that were published in the draft Preparatory Study (labelled as "VITO" in the graphic). The amorphous designs prepared by CLASP have been given a different shaped symbol to more easily identify them. VITO did not publish any amorphous designs for the 2000 kVA unit.

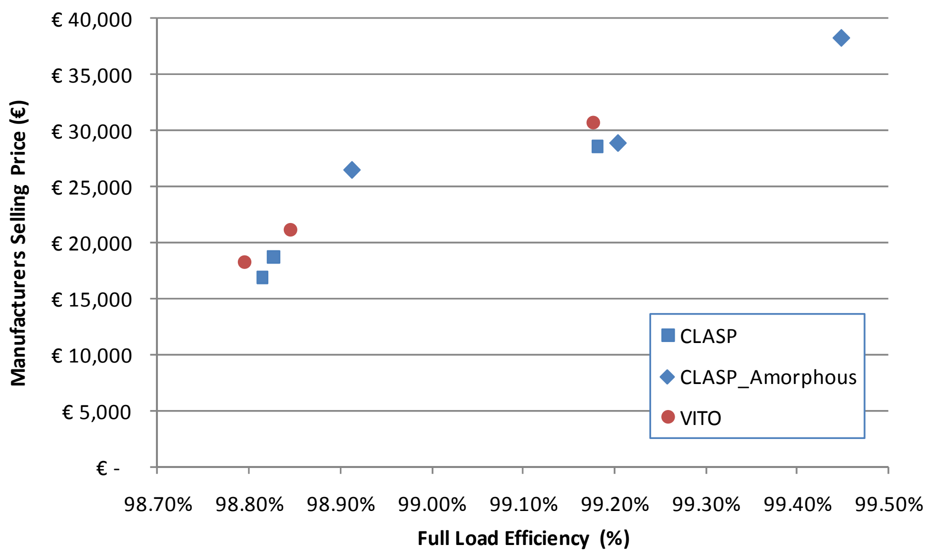


Figure 1-4. Price vs. Efficiency of VITO and CLASP 2000 kVA Oil-Immersed Transformers

The designs published by VITO using conventional electrical steel appear to be slightly higher than the manufacturing cost estimates prepared from the 2000 kVA transformer designs commissioned by CLASP.

The table below presents tabular results and the corresponding relative prices for the designs under consideration for the 2000 kVA transformer.

Table 1-6. Indexed Price Increases Relative to Baseline for CLASP's Designs, 2000 kVA

BC5 – DER Oil-immersed Transformer 2000 kVA		E0	D0	C0	B0	A0	Amorph.
		3100 W	2700 W	2100 W	1800 W	1450 W	850 W
Dk	26000 W						
Ck	21000 W	100%		111%			157%
Bk	18000 W						
Ak	15000 W					168%	171%
Best Tech	10100 W						226%

In addition, CLASP prepared a "best technology" design for this unit with core losses at 850W and significantly lower winding losses, at 10,100W. The core losses on this 2000 kVA transformer are reduced by 72% and the winding losses are reduced by 52% relative to the base case E0Ck design. This particular design represents an indexed price of 226%, which is slightly more than double the cost of the baseline E0Ck unit.

The table below compares the transformer designs prepared on a cost basis and looks at the difference. On average, the CLASP transformers are approximately 8.5% less expensive than those published in the draft Preparatory Study. These data demonstrate that there is a good price-efficiency correlation between the CLASP and VITO designs for the grain-oriented electrical steels.

Table 1-7. Price Comparison of 2000 kVA Transformer Designs

Design Losses		CLASP Designs		VITO Designs		Difference of CLASP Relative to VITO
Core (P0)	Coil (Pk)	Efficiency	Price	Efficiency	Price	
3100	21 000	98.81%	€ 16,938	98.80%	€ 18,248	-7.2%
2100	21 000	98.83%	€ 18,729	98.85%	€ 21,168	-11.5%
1450	15 000	99.18%	€ 28,537	99.18%	€ 30,657	-6.9%
850*	21 000	98.91%	€ 26,518			
850*	15 000	99.20%	€ 28,903			
850*	10 100	99.45%	€ 38,221			

* Amorphous core transformer designs.

Improving efficiency from the base case model of E0Ck (3100W, 21000W) up to A0Ak (1450W, 15000W) has a cost per one-hundredth percent improvement in efficiency of approximately €320 for both the CLASP designs and the VITO designs. In other words, the slopes that define the relationship between the manufacturer selling price and efficiency are similar. Furthermore, CLASP's database includes amorphous designs which reach higher efficiencies at competitive prices with conventional electrical steels, such as the 99.20% and 99.45% designs shown above.

2 Methodology and Inputs

To provide a review of the relationship between price and efficiency for European Commission's analysis of Transmission and Distribution Transformers, CLASP undertook a study of three of the seven base case transformers being evaluated in LOT 2 by DG Enterprise. The three transformers studied are:

- 400 kVA oil-immersed three-phase unit, representing distribution transformers
- 1000 kVA oil-immersed three-phase unit, representing industry transformers
- 2000 kVA oil-immersed three-phase unit, representing distributed energy resources (DER) transformers

CLASP commissioned the development of 28 transformer designs spanning a range of efficiency levels across these three transformers. In each case, both stacked core and wound core designs were prepared, the stacked cores use grain-oriented electrical steel and the wound core designs use amorphous material.

The designs were based initially on a baseline unit, typically constructed with M6 core steel, a copper primary and aluminium secondary. Materials would then be substituted that would improve the efficiency, such as better core steels (e.g., M3, M2, laser-scribed domain-refined (HO), and amorphous (SA1)), winding materials (e.g., switching from aluminium to copper), and lower loss designs.

2.1 Methodology Followed

For the three base case models, this analysis explored the relationship between the manufacturer selling prices and corresponding transformer efficiencies. To prepare these designs, CLASP contracted Optimized Program Service, Inc. (OPS) in Ohio, a software company specializing in transformer design since 1969. To ensure that the resultant designs are relevant in a European context, CLASP also contracted Eoin Carey, a former ABB transformer design engineer based in Ireland with more than 20 years design experience.

Using a range of input parameters and material prices, the OPS software prepares a cost-optimised design with the requested core and coil losses and impedance. This design file produced by the software has specific information about the core and coil, including physical characteristics, dimensions, material requirements and mechanical clearances, as well as a complete electrical analysis of the final design. This practical transformer design, the bill of materials, and an electrical analysis report contain sufficient information for a manufacturer to build the unit. The software's output is used to generate an estimated cost of manufacturing materials and labour, which is then converted to a manufacturer's selling price by applying mark-ups.

2.1.1 Optimized Program Service

Optimized Program Service[1] began in 1969 to provide comprehensive design tools for the transformer industry that blend magnetic design theory with practical manufacturing experience. The programmes have been used for more than 40 years by manufacturers and specifiers throughout the United States, Canada, Mexico, Europe, China, India, and Egypt. Continued enhancement, testing, and verification of the programmes assure realistic and practical design results.

OPS focuses exclusively on transformer design, working collaboratively with manufacturers and receiving feedback on units manufactured. OPS supported the US Department of Energy's Distribution Transformer energy conservation standard rulemaking, which was completed in October 2007. Throughout that public consultative process, OPS provided engineering support that was reviewed and accepted by the North American transformer industry as being reasonable and representative of the manufacturing market.

OPS's role in this project was to conduct the following:

1. Work with Eoin Carey (other subcontractor working on this study) to set-up six designs - three stacked and three wound - for the representative units.
2. Develop 28 transformer designs with losses that are within 10% of the target values given in the European Standards. Provide standard output from the OPS software for core and coil information for the 28 designs.
3. Provide electrical performance characteristics including losses at full load, volts/turn, current density, impedance, etc.
4. Provide a bill of materials including kg of steel or amorphous material, kilograms of wire, volume of cooling fluid, winding form, insulation, etc.
5. Provide information on the cooling surface area, including whether the transformers require radiators.

2.1.2 Eoin Carey

Eoin is a highly experienced transformer engineer with over 20 years experience in best practice engineering and management disciplines for his former employer, ABB, a global transformer company. Based out of Waterford, Ireland, Eoin has worked across product design, process engineering, automation and manufacturing. He's served as a key member of an international ABB team that developed the common technology design system for liquid wound core transformers, and prepared complete electrical and mechanical designs of distribution transformers for utility and industrial customers. He has experience working on product costing, the preparation of quotes, and material and purchase specifications.

For CLASP, Eoin's role was to conduct the following:

1. Finalise the specification of the three representative units (e.g., voltages, taps, impedance), ensuring this specification is typical of European transformers.

[1] The OPS website can be found at: http://www.opsprograms.com/

2. Provide the necessary inputs to OPS to create the base line stacked and wound-core designs for the 400 kVA, 1000 kVA and 2000 kVA units.
3. Review the output from the OPS software for the 28 designs and provide feedback to OPS on any necessary changes to make the designs typical of what might be found in Europe.
4. Assist Navigant with pricing for tanks, bracing, straps, bushings and other hardware costs. Review and comment on labour cost estimates.

2.2 Input Assumptions

In preparing the designs, OPS used five different grain-oriented electrical steels as well as amorphous material. The table below provides the thickness and performance information for these steels. From this table its clear to see that as better (and more expensive) core steels are used, the watts of energy lost per pound of core steel decrease. The measurement of watts per pound of core steel are presented at fixed levels of magnetic flux – 1.3, 1.5 and 1.7 Tesla.

Table 2-1. Core Steels Used to Improve the Efficiency of the Oil-Immersed Transformers

Steel	Thickness (mm)	Losses per Pound (Watts/kg)	Description
M6	0.35	1.46 W/kg at 1.5 T 2.07 W/kg at 1.7 T	Grain-oriented silicon steel
M4	0.27	1.12 W/kg at 1.5 T 1.63 W/kg at 1.7 T	Grain-oriented silicon steel
M3	0.23	0.98 W/kg at 1.5 T 1.54 W/kg at 1.7 T	Grain-oriented silicon steel
M2	0.18	0.89 W/kg at 1.5 T	Grain-oriented silicon steel
H-0 DR	0.23	1.32 W/kg at 1.7 T	"Domain-refined, high permeability" grade silicon steel, laser-scribed
SA1	0.025	0.18 W/kg at 1.3 T	Amorphous core steel (silicon and boron); flux density limitation - testing at 1.3 T

The following table presents the prices of materials used in transformer manufacturing. These prices were published in Chapter 2 of the July 2010 revised preparatory study, and reflect an adaptation of material prices previously published by the US Department of Energy in 2007 with review and correction / input by European transformer manufacturers. The prices are presented in two columns – the price that manufacturers pay for the material (i.e., the business to business cost), and the marked-up price representing what that material is worth when the transformer manufacturer sells the transformer to a customer. When running the design optimisation programme, the marked-up prices are used, however when preparing an estimate of the cost of manufacture, the non-marked up prices are used.

Table 2-2. Material Prices Published in Chapter 2 of Preparatory Study (July 2010)

Oil-immersed transformers	2002-2006 average 5 year material price in €/kg	2002-2006 average 5 year marked up material price in €/kg
M2 core steel	1.96	2.82
M3 core steel	1.79	2.58
M4 core steel	1.72	2.48
M5 core steel	about 3.00	
M6 core steel	1.55	2.23
mechanically-scribed core steel	2.75	3.95
amorphous -finished core, volume production	2.5 -3.61	5.17
copper wire, formvar, round 10-20	4.36	6.3
copper wire, enamelled, round 7-10 flattened	4.42	6.37
copper wire, enamelled, rectangular sizes	4.73	6.82
aluminum wire. formvar. round 9-17	2.58	3.72
aluminum wire. formvar. round 7-10	2.62	3.77
copper strip. thickness range 0.020-0.045	4.54	6.55
copper strip. thickness range 0.030-0.060	4.41	6.35
aluminum strip. thickness range 0.020-0.045	2.87	4.14
aluminum strip. thickness range 0.045-0.080	2.82	4.07
kraft insulation paper with diamond adhesive	2.79	4.02
mineral oil (per liter)	1	1.5
tank steel	0.74	1.08
Dry-type transformers		
domain refined core steel	2.14	3.11
M3 core steel	1.81	2.6
M4 core steel	1.72	2.48
M5 core steel	1.64	2.36
M6 core steel	1.6	2.31
M19 core steel (26 gauge)	1.03	1.49
M36 core steel (29 gauge)	0.95	1.35
M36 core steel (26 gauge)	0.86	1.25
M43 core steel (26 gauge)	0.81	1.18
rectangular copper wire 0.1 x 0.2. Nomex	4.85	6.99

Although they are based on data from the United States, the mark-ups used in this table were also applied to the raw material costs in this analysis of European transformers. The manufacturer's selling price is equal to the full production cost, which is a combination of direct labour, direct materials, and overhead plus the non-production costs. The overheads contributing to full production cost includes indirect labour, indirect material, maintenance, depreciation, taxes, and insurance related to company assets. Non-production costs include the cost of selling (market research, advertising, sales representatives, logistics), general and administrative costs, research and development (R&D), interest payments, and profit.

In its analysis published in September 2007, the US Department of Energy used a series of mark-ups that were intended to represent reasonable averages for the transformer manufacturing industry. The following mark-ups resulted:

- Scrap and handling factor: 2.5 percent mark-up. This mark-up applies to variable materials (e.g., core steel, windings, insulation). It accounts for the handling of material (loading into assembly or winding equipment) and the scrap material that cannot be used in the production of a finished transformer (e.g., lengths of wire too short to wind, trimmed core steel). Material handling is tracked as labour and represents 1.5% of the material and the scrap is calculated as material and is calculated as 1% of the material.

- Factory overhead: 12.5 percent mark-up. Factory overhead includes all the indirect costs associated with production, indirect materials and energy use (e.g., annealing furnace), taxes, and insurance. Factory overhead is only applies to the direct material production costs.

- Non-production: 25 percent mark-up. This mark-up reflects costs including selling, general and administrative, R&D, interest payments, and profit factor. The Department applied the non-production mark-up to the sum of direct material, direct labour, and factory overhead.

The application of these mark-ups can be found in the bill of materials (BOM) tables presented in Chapters 3, 4 and 5 of this report.

2.3 Design Assumptions for 400 kVA

Basecase Transformer #1 (BC1) represents oil-immersed distribution transformers. The rating selected for this basecase is the 400 kVA three-phase transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

Type: Oil-immersed, Three-Phase
KVA: 400
Primary: 11 kilovolts at 50 Hz
Secondary: 400 volts
T Rise: 60/65°C (above ambient, assumed 25°C)
Winding Configuration: Lo-Hi
Cores: Grain-oriented electrical steel in stacked configuration (3-leg); Amorphous material in wound core – DG, 5-leg
Taps: +/- 2 x 2.5%
Impedance: 4%

VITO developed and published a matrix of core and winding losses based on EN 50464-1 as a survey tool to facilitate input from manufacturers on the relationship between price and efficiency. The table presented below contains the loss and price information for the 400kVA transformer. VITO requested input from manufacturers on the percentage price increase for each of the incremental improvements from the Eff0 transformer. To facilitate a comparison with the draft Preparatory Study, CLASP adopted this approach when engaging its design team to prepare the designs presented in this report.

Table 2-3. VITO Survey Tool to Quantify Price Increases Relative to Efficiency, 400 kVA

BC1 – Distribution Transformer 400 kVA		E0	D0	C0	B0	A0	Amorph.
		930 W	750 W	610 W	520 W	430 W	?
Dk	6000 W						
Ck	4600 W		100%	?	?	?	?
Bk	3850 W				?	?	?
Ak	3250 W					?	?

From this table, CLASP determined that it needed to develop the following list of designs for this kVA rating:

Eff0: Po: 750W; Pk 4600W – stacked core
Eff1: Po: 610W; Pk 4600W – stacked core
Eff2: Po: 520W; Pk 4600W – stacked core
Eff3: Po: 520W; Pk 3850W – stacked core
Eff4: Po: 430W; Pk 4600W – stacked core
Eff5: Po: 430W; Pk 3850W – stacked core
Eff6: Po: 430W; Pk 3250W – stacked core
Eff7: Po: <<430W; Pk 4600W – wound core (amorphous)
Eff8: Po: <<430W; Pk 3850W – wound core (amorphous)
Eff9: Po: <<430W; Pk 3250W – wound core (amorphous)
Eff10: Po: <<430W; Pk <<3250W – wound core (amorphous) – best technology

2.4 Design Assumptions for 1000 kVA

Basecase Transformer #2 (BC2) represents oil-immersed industrial transformers. The rating selected for this basecase is the 1000 kVA three-phase transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

Type: Oil-immersed, Three-Phase
KVA: 1000
Primary: 11 kilovolts at 50 Hz
Secondary: 400 volts
T Rise: 60/65°C (above ambient, assumed 25°C)
Winding Configuration: Lo - Hi
Cores: Grain-oriented electrical steel in stacked configuration (3-leg); Amorphous material in wound core – DG, 5-leg
Taps: +/- 2 x 2.5%
Impedance: 6%

VITO developed and published a matrix of core and winding losses based on EN 50464-1 as a survey tool to facilitate input from manufacturers on the relationship between price and efficiency. The table presented below contains the loss and price information for the

1000kVA transformer. VITO requested input from manufacturers on the percentage price increase for each of the incremental improvements from the Eff0 transformer. To facilitate a comparison with the draft Preparatory Study, CLASP adopted this approach when engaging its design team to prepare the designs presented in this report.

Table 2-4. VITO Survey Tool to Quantify Price Increases Relative to Efficiency, 1000 kVA

BC2 – Industry Transformer 1000 kVA		E0	D0	C0	B0	A0	Amorph.
		1700 W	1400 W	1100 W	940 W	770 W	?
Dk	13 000 W						
Ck	10 500 W	100%		?	?	?	?
Bk	9000 W				?	?	?
Ak	7600 W					?	?

From this table, CLASP determined that it needed to develop the following list of designs for this kVA rating:

Eff0: Po: 1700W; Pk 10500W – stacked core
Eff1: Po: 1100W; Pk 10500W – stacked core
Eff2: Po: 940W; Pk 10500W – stacked core
Eff3: Po: 940W; Pk 9000W – stacked core
Eff4: Po: 770W; Pk 10500W – stacked core
Eff5: Po: 770W; Pk 9000W – stacked core
Eff6: Po: 770W; Pk 7600W – stacked core
Eff7: Po: <<770W; Pk 10500W – wound core (amorphous)
Eff8: Po: <<770W; Pk 9000W – wound core (amorphous)
Eff9: Po: <<770W; Pk 7600W – wound core (amorphous)
Eff10: Po: <<770W; Pk <<7600W – wound core (amorphous) – best technology

2.5 Design Assumptions for 2000 kVA

Basecase Transformer #5 (BC5) represents oil-immersed distributed energy resources (DER) transformers, such as might be found at a wind-turbine site. The rating selected for this basecase is the 2000 kVA three-phase transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

Type: Oil-immersed, Three-Phase
KVA: 2000
Primary: 24 kilovolts at 50 Hz
Secondary: 0.69 kilovolts
T Rise: 60/65°C (above ambient, assumed 25°C)
Winding Configuration: Lo - Hi
Cores: Grain-oriented electrical steel in stacked configuration (3-leg); Amorphous material in wound core – DG, 5-leg

Taps: +/- 2 x 2.5%
Impedance: 6%

VITO developed and published a matrix of core and winding losses based on EN 50464-1 as a survey tool to facilitate input from manufacturers on the relationship between price and efficiency. The table presented below contains the loss and price information for the 2000kVA transformer. VITO requested input from manufacturers on the percentage price increase for each of the incremental improvements from the Eff0 transformer. To facilitate a comparison with the draft Preparatory Study, CLASP adopted this approach when engaging its design team to prepare the designs presented in this report.

Table 2-5. VITO Survey Tool to Quantify Price Increases Relative to Efficiency, 2000 kVA

BC5 – DER Oil-immersed Transformer 2000 kVA		E0	D0	C0	B0	A0	Amorph.
		3100 W	2700 W	2100 W	1800 W	1450 W	?
Dk	26000 W						
Ck	21000 W	100%		?			?
Bk	18000 W						
Ak	15000 W					?	?

From this table, CLASP determined that it needed to develop the following list of designs for this kVA rating:

Eff0: Po: 3100W; Pk 21000W – stacked core
Eff1: Po: 2100W; Pk 21000W – stacked core
Eff2: Po: 1450W; Pk 15000W – stacked core
Eff3: Po: <<1450W; Pk 21000W – wound core (amorphous)
Eff4: Po: <<1450W; Pk 15000W – wound core (amorphous)
Eff5: Po: <<1450W; Pk <<15000W – wound core (amorphous) - best technology

3 Designs for 400 kVA Transformer

The cost of a 400 kVA increases with improvements in the efficiency, as shown in the table below.

Table 3-1. CLASP Designs Prepared for 400 kVA Transformer

	EFF0	EFF1	EFF2	EFF3	EFF4	EFF5	EFF6	EFF7	EFF8	EFF9	EFF10
Power rating:	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA
Phases:	3	3	3	3	3	3	3	3	3	3	3
Number of legs:	3-legged	3-legged	3-legged	3-legged	3-legged	3-legged	3-legged	5-legged	5-legged	5-legged	5-legged
Frequency:	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz
Primary (kV)	11	11	11	11	11	11	11	11	11	11	11
Secondary (Volts)	400	400	400	400	400	400	400	400	400	400	400
T rise (deg C):	65	65	65	65	65	65	65	65	65	65	65
Ambient (deg C):	20	20	20	20	20	20	20	20	20	20	20
Winding Configration:	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi
Core:	Stacked	Stacked	Stacked	Stacked	Stacked	Stacked	Stacked	Wound	Wound	Wound	Wound
Core Type:	Mitered	Mitered	Mitered	Mitered	Mitered	Mitered	Mitered	DG	DG	DG	DG
Core Mat'l:	M6	M4	M3	M3	HO	HO	HO	SA1	SA1	SA1	SA1
HV Conductor Mat'l:	CU	CU	CU	CU	CU	CU	CU	CU	CU	CU	CU
LV Conductor Mat'l:	AL	AL	AL	CU	CU	CU	CU	AL	AL	AL	CU
Core Losses:	737	599	507	507	411	417	424	196	219	219	216
Coil Losses:	4699	4713	4711	3811	4513	3956	3347	4554	3898	3324	2508
Efficiency (100% load):	98.64%	98.67%	98.70%	98.92%	98.77%	98.91%	99.06%	98.81%	98.97%	99.11%	99.32%
Selling Price:	€ 5,825	€ 6,079	€ 6,146	€ 8,312	€ 7,711	€ 7,821	€ 8,891	€ 7,516	€ 8,740	€ 9,304	€ 11,252
% Increase over Eff0:	0%	4%	6%	43%	32%	34%	53%	29%	50%	60%	93%

Two designs were selected from this database of designs for presentation in this chapter of the report, providing detail on the bill of materials and the performance of the designs. The two designs selected were:

- EFF1 – a 400 kVA unit built with M4 core steel in a cruciform oval stack, with losses of approximately 610W in the core and 4600W in the coil at full load.

- EFF9 – a 400 kVA unit built with amorphous material (SA1) in a wound-core configuration with losses of approximately 340W in the core and 3250W in the coil at full load.

3.1 BOM for 400 kVA M4 in a Cruciform Oval Stack

The following table provides the bill of materials that was calculated from the OPS design details report (see Annex A). This bill of materials uses the raw material prices given in section 2.2 of this report, which are derived from the draft Preparatory Study. These materials are then marked up at the bottom of the table to allow for factory overheads and non-production mark-ups (see section 2.2 of this report). The sum of the raw material costs, labour costs and mark-ups totals to the manufacturer's selling price. This table provides the bill of materials for 400 kVA transformer with M4 core steel, built in a cruciform stack. This transformer has an 11kV primary with copper wire and 400V secondary with aluminium strip.

Table 3-2. Bill of Materials and Labour for 400 kVA M4 in a Cruciform Oval Stack

Material item	Type	Quantity	Each	Total
Core material*	M4 Grain-Oriented Silicon Stee	698	€ 1.72	€ 1,201
Primary Winding*	Copper Round (kg)	193	€ 4.42	€ 852
Secondary Winding*	Aluminium strip (kg)	94	€ 2.87	€ 271
Winding form & insulation*	Paper with diamond adhesive	21	€ 2.79	€ 59
Coolant / Dielectric	Mineral oil (litres)	468	€ 1.00	€ 468
Tank and Radiator		1	€ 500.00	€ 500
High Voltage Bushing	10Nf250 HV to DIN 42531	3	€ 25.00	€ 75
Low Voltage Bushing	1000A clamped bushings	4	€ 20.00	€ 80
Hardware and Clamps	misc. & nameplate		€ 61.00	€ 61
Scrap factor (applies to items with * above)			1.00%	€ 24
		Total Material Cost		€ 3,590
Labour item	**Description**	**Hours**	**€/hr**	**Total**
Lead Dressing	Prepare leads after winding	0.67	€ 60.00	€ 40
Handling and Slitting	Working with core steel	0.60	€ 60.00	€ 36
Winding the Primary	Varies with N turns	3.71	€ 60.00	€ 223
Winding the Secondary	Varies with N turns	1.56	€ 60.00	€ 94
Inspection	Quality assurance check	0.20	€ 60.00	€ 12
Baking Coils	Remove air/moisture	0.15	€ 60.00	€ 9
Cutting, Forming, and Annealing	Core steel, varies with grade	0.37	€ 60.00	€ 22
Core Assembly	Assemble around coils, varies	1.02	€ 60.00	€ 61
Tanking and Final Assembly	Attach radiator, pull vaccuum	1.30	€ 60.00	€ 78
Preliminary Test on Windings	Check turns ratio, resistance	0.15	€ 60.00	€ 9
Final Test	Assembled unit test	0.25	€ 60.00	€ 15
Packing and Pallet Loading	Clamping, wrapping and other s	3.00	€ 60.00	€ 180
Marking and Miscellaneous	Labelling bushings, etc.	0.75	€ 60.00	€ 45
		Total Labour Cost		€ 824
Manufacturing Cost (Total Material & Total Labour)				€ 4,414
Factory Overhead (Applied to Material Costs Only)		12.5%		€ 449
Non-production Cost Markup		25%		€ 1,216
Manufacturer Selling Price				€ 6,079

3.2 BOM for 400 kVA Amorphous in a Wound Core Configuration

The following table provides the bill of materials that was calculated from the OPS design details report (see Annex A). This bill of materials uses the raw material prices given in section 2.2 of this report, which are derived from the draft Preparatory Study. These materials are then marked up at the bottom of the table to allow for factory overheads and non-production mark-ups (see section 2.2 of this report). The sum of the raw material costs, labour costs and mark-ups totals to the manufacturer's selling price. This table provides the bill of materials for 400 kVA transformer with amorphous material, built in a wound core configuration. This transformer has an 11kV primary with copper wire and 400V secondary with aluminium strip.

Table 3-3. Bill of Materials and Labour for 400 kVA Amorphous Wound Core

Material item	Type	Quantity	Each	Total
Core material*	Amorphous Material	865	€ 3.00	€ 2,595
Primary Winding*	Copper (kg)	336	€ 4.42	€ 1,484
Secondary Winding*	Aluminium strip (kg)	123	€ 2.87	€ 352
Winding form & insulation*	Paper with diamond adhesive	32	€ 2.79	€ 90
Coolant / Dielectric	Mineral oil (litres)	602	€ 1.00	€ 602
Tank and Radiator		1	€ 500.00	€ 500
High Voltage Bushing	10Nf250 HV to DIN 42531	3	€ 25.00	€ 75
Low Voltage Bushing	1000A clamped bushings	4	€ 20.00	€ 80
Hardware and Clamps	misc. & nameplate		€ 61.00	€ 61
Scrap factor (applies to items with * above)			1.00%	€ 45
		Total Material Cost		€ 5,884
Labour item	**Description**	**Hours**	**€/hr**	**Total**
Lead Dressing	Prepare leads after winding	0.67	€ 60.00	€ 40
Handling and Slitting	Working with core steel	1.13	€ 60.00	€ 68
Winding the Primary	Varies with N turns	3.43	€ 60.00	€ 206
Winding the Secondary	Varies with N turns	1.44	€ 60.00	€ 86
Inspection	Quality assurance check	0.20	€ 60.00	€ 12
Baking Coils	Remove air/moisture	0.15	€ 60.00	€ 9
Core Assembly	Assemble around coils, varies	1.27	€ 60.00	€ 76
Tanking and Final Assembly	Attach radiator, pull vaccuum	1.30	€ 60.00	€ 78
Preliminary Test on Windings	Check turns ratio, resistance	0.15	€ 60.00	€ 9
Final Test	Assembled unit test	0.25	€ 60.00	€ 15
Packing and Pallet Loading	Clamping, wrapping and other s	3.00	€ 60.00	€ 180
Marking and Miscellaneous	Labelling bushings, etc.	0.75	€ 60.00	€ 45
		Total Labour Cost		€ 824
Manufacturing Cost (Total Material & Total Labour)				€ 6,708
Factory Overhead (Applied to Material Costs Only)		12.5%		€ 735
Non-production Cost Markup		25%		€ 1,861
Manufacturer Selling Price				€ 9,304

4 Designs for 1000 kVA Transformer

The cost of a 1000 kVA increases with improvements in the efficiency, as shown in the table below.

Table 4-1. CLASP Designs Prepared for 1000 kVA Transformer

	EFF0	EFF1	EFF2	EFF3	EFF4	EFF5	EFF6	EFF7	EFF8	EFF9	EFF10
Power rating:	1000 kVA	1000 kVA	1000 kVA	1000 kVA	1000 kVA	1000 kVA	1000 kVA	1000 kVA	1000 kVA	1000 kVA	1000 kVA
Phases:	3	3	3	3	3	3	3	3	3	3	3
Number of legs:	3-legged	3-legged	3-legged	3-legged	3-legged	3-legged	3-legged	5-legged	5-legged	5-legged	5-legged
Frequency:	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz
Primary (kV)	11	11	11	11	11	11	11	11	11	11	11
Secondary (Volts)	400	400	400	400	400	400	400	400	400	400	400
T rise (deg C):	65	65	65	65	65	65	65	65	65	65	65
Ambient (deg C):	20	20	20	20	20	20	20	20	20	20	20
Winding Configration:	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi
Core:	Stacked	Stacked	Stacked	Stacked	Stacked	Stacked	Stacked	Wound	Wound	Wound	Wound
Core Type:	Mitered	Mitered	Mitered	Mitered	Mitered	Mitered	Mitered	DG	DG	DG	DG
Core Mat'l:	M6	M3	M2	M2	M2	HO	HO	SA1	SA1	SA1	SA1
HV Conductor Mat'l:	CU	CU	CU	CU	CU	CU	CU	CU	CU	CU	CU
LV Conductor Mat'l:	AL	AL	AL	CU	CU	CU	CU	AL	AL	AL	CU
Core Losses:	1637	1073	920	930	750	729	737	383	413	417	411
Coil Losses:	10433	10470	10855	9161	10421	9340	7637	10779	9096	7789	5992
Efficiency (100% load):	98.79%	98.85%	98.82%	98.99%	98.88%	98.99%	99.16%	98.88%	99.05%	99.18%	99.36%
Selling Price:	€ 9,270	€ 9,827	€ 11,177	€ 13,396	€ 15,066	€ 16,716	€ 18,398	€ 15,538	€ 17,166	€ 18,484	€ 23,570
% Increase over Eff0:	0%	6%	21%	45%	63%	80%	98%	68%	85%	99%	154%

Two designs were selected from this database of designs for presentation in this chapter of the report, providing detail on the bill of materials and the performance of the designs. The two designs selected were:

- EFF2 – a 1000 kVA unit built with M2 core steel in a cruciform oval stack, with losses of approximately 940W in the core and 10,500W in the coil at full load.
- EFF9 – a 1000 kVA unit built with amorphous material (SA1) in a wound-core configuration with losses of approximately 650W in the core and 7600W in the coil at full load.

4.1 BOM for 1000 kVA M2 in a Cruciform Oval Stack

The following table provides the bill of materials that was calculated from the OPS design details report (see Annex B). This bill of materials uses the raw material prices given in section 2.2 of this report, which are derived from the draft Preparatory Study. These materials are then marked up at the bottom of the table to allow for factory overheads and non-production mark-ups (see section 2.2 of this report). The sum of the raw material costs, labour costs and mark-ups totals to the manufacturer's selling price. This table provides the bill of materials for 1000 kVA transformer with M2 core steel, built in a cruciform stack. This transformer has an 11kV primary with copper wire and 400V secondary with aluminium strip.

Table 4-2. Bill of Materials and Labour for 1000 kVA M2 in a Cruciform Oval Stack

Material item	Type	Quantity	Each	Total
Core material*	M2 Grain-Oriented Silicon Stee	1,437	€ 1.96	€ 2,816
Primary Winding*	Copper wire (kg)	381	€ 4.42	€ 1,682
Secondary Winding*	Aluminium strip (kg)	150	€ 2.87	€ 429
Winding form & insulation*	Paper with diamond adhesive	39	€ 2.79	€ 108
Coolant / Dielectric	Mineral oil (litres)	943	€ 1.00	€ 943
Tank and Radiator		1	€ 800.00	€ 800
High Voltage Bushing	10Nf250 HV to DIN 42531	3	€ 25.00	€ 75
Low Voltage Bushing	2000A clamped bushings	4	€ 20.00	€ 80
Hardware and Clamps	misc. & nameplate		€ 121.00	€ 121
Scrap factor (applies to items with * above)			1.00%	€ 50
		Total Material Cost		€ 7,105
Labour item	**Description**	**Hours**	**€/hr**	**Total**
Lead Dressing	Prepare leads after winding	0.75	€ 60.00	€ 45
Handling and Slitting	Working with core steel	1.26	€ 60.00	€ 76
Winding the Primary	Varies with N turns	3.65	€ 60.00	€ 219
Winding the Secondary	Varies with N turns	1.02	€ 60.00	€ 61
Inspection	Quality assurance check	0.20	€ 60.00	€ 12
Baking Coils	Remove air/moisture	0.15	€ 60.00	€ 9
Cutting, Forming, and Annealing	Core steel, varies with grade	0.98	€ 60.00	€ 59
Core Assembly	Assemble around coils, varies	2.11	€ 60.00	€ 126
Tanking and Final Assembly	Attach radiator, pull vaccuum	1.55	€ 60.00	€ 93
Preliminary Test on Windings	Check turns ratio, resistance	0.15	€ 60.00	€ 9
Final Test	Assembled unit test	0.25	€ 60.00	€ 15
Packing and Pallet Loading	Clamping, wrapping and other s	3.00	€ 60.00	€ 180
Marking and Miscellaneous	Labelling bushings, etc.	0.75	€ 60.00	€ 45
		Total Labour Cost		€ 949
Manufacturing Cost (Total Material & Total Labour)				€ 8,054
Factory Overhead (Applied to Material Costs Only)		12.5%		€ 888
Non-production Cost Markup		25%		€ 2,235
Manufacturer Selling Price				€ 11,177

4.2 BOM for 1000 kVA SA1 Amorphous Material in Wound Core Configuration

The following table provides the bill of materials that was calculated from the OPS design details report (see Annex B). This bill of materials uses the raw material prices given in section 2.2 of this report, which are derived from the draft Preparatory Study. These materials are then marked up at the bottom of the table to allow for factory overheads and non-production mark-ups (see section 2.2 of this report). The sum of the raw material costs, labour costs and mark-ups totals to the manufacturer's selling price. This table provides the bill of materials for 1000 kVA transformer with amorphous material, built in a wound core configuration. This transformer has an 11kV primary with copper wire and 400V secondary with aluminium strip.

Table 4-3. Bill of Materials and Labour for 1000 kVA Amorphous Wound Core

Material item	Type	Quantity	Each	Total
Core material*	Amorphous Material	1,693	€ 3.00	€ 5,080
Primary Winding*	Copper wire (kg)	809	€ 4.42	€ 3,576
Secondary Winding*	Aluminium strip (kg)	324	€ 2.87	€ 929
Winding form & insulation*	Paper with diamond adhesive	81	€ 2.79	€ 225
Coolant / Dielectric	Mineral oil (litres)	1,124	€ 1.00	€ 1,124
Tank and Radiator		1	€ 975.00	€ 975
High Voltage Bushing	10Nf250 HV to DIN 42531	3	€ 25.00	€ 75
Low Voltage Bushing	2000A clamped bushings	4	€ 20.00	€ 80
Hardware and Clamps	misc. & nameplate		€ 121.00	€ 121
Scrap factor (applies to items with * above)			1.00%	€ 98
		Total Material Cost		€ 12,284
Labour item	**Description**	**Hours**	**€/hr**	**Total**
Lead Dressing	Prepare leads after winding	0.75	€ 60.00	€ 45
Handling and Slitting	Working with core steel	2.45	€ 60.00	€ 147
Winding the Primary	Varies with N turns	3.43	€ 60.00	€ 206
Winding the Secondary	Varies with N turns	0.96	€ 60.00	€ 58
Inspection	Quality assurance check	0.20	€ 60.00	€ 12
Baking Coils	Remove air/moisture	0.15	€ 60.00	€ 9
Core Assembly	Assemble around coils, varies	2.48	€ 60.00	€ 149
Tanking and Final Assembly	Attach radiator, pull vaccuum	1.55	€ 60.00	€ 93
Preliminary Test on Windings	Check turns ratio, resistance	0.15	€ 60.00	€ 9
Final Test	Assembled unit test	0.25	€ 60.00	€ 15
Packing and Pallet Loading	Clamping, wrapping and other s	3.00	€ 60.00	€ 180
Marking and Miscellaneous	Labelling bushings, etc.	0.75	€ 60.00	€ 45
		Total Labour Cost		€ 968
Manufacturing Cost (Total Material & Total Labour)				€ 13,251
Factory Overhead (Applied to Material Costs Only)		12.5%		€ 1,535
Non-production Cost Markup		25%		€ 3,697
Manufacturer Selling Price				€ 18,484

5 Designs for 2000 kVA Transformer

The cost of a 2000 kVA increases with improvements in the efficiency, as shown in the table below.

Table 5-1. CLASP Designs Prepared for 2000 kVA Transformer

	EFF0	EFF1	EFF2	EFF3	EFF4	EFF5
Power rating:	2000	2000	2000	2000	2000	2000
Phases:	3	3	3	3	3	3
Number of legs:	3-legged	3-legged	3-legged	5-legged	5-legged	5-legged
Frequency:	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz
Primary (kV)	24	24	24	24	24	24
Secondary (Volts)	690	690	690	690	690	690
T rise (deg C):	65	65	65	65	65	65
Ambient (deg C):	20	20	20	20	20	20
Winding Configration:	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi	Lo-Hi
Core:	Stacked	Stacked	Stacked	Wound	Wound	Wound
Core Type:	Mitered	Mitered	Mitered	DG	DG	DG
Core Mat'l:	M6	M4	HO	SA1	SA1	SA1
HV Conductor Mat'l:	CU	CU	CU	CU	CU	CU
LV Conductor Mat'l:	AL	AL	CU	AL	AL	CU
Core Losses:	3000	2070	1428	812	857	914
Coil Losses:	20709	21403	14938	20927	15057	10107
Efficiency (100% load):	98.81%	98.83%	99.18%	98.91%	99.20%	99.45%
Selling Price:	€ 16,938	€ 18,729	€ 28,537	€ 26,518	€ 28,903	€ 38,221
% Increase over Eff0:	0%	11%	68%	57%	71%	126%

Two designs were selected from this database of designs for presentation in this chapter of the report, providing detail on the bill of materials and the performance of the designs. The two designs selected were:

- EFF1 – a 2000 kVA unit built with M4 core steel in a cruciform oval stack, with losses of approximately 2100W in the core and 21000W in the coil at full load.

- EFF4 – a 2000 kVA unit built with amorphous material (SA1) in a wound-core configuration with losses of approximately 1150W in the core and 15000W in the coil at full load.

5.1 BOM for 2000 kVA M4 in a Cruciform Oval Stack

The following table provides the bill of materials that was calculated from the OPS design details report (see Annex C). This bill of materials uses the raw material prices given in section 2.2 of this report, which are derived from the draft Preparatory Study. These materials are then marked up at the bottom of the table to allow for factory overheads and non-production mark-ups (see section 2.2 of this report). The sum of the raw material costs, labour costs and mark-ups totals to the manufacturer's selling price. This table provides the bill of materials for 2000 kVA transformer with M4 core steel, built in a cruciform stack. This transformer has a 24kV primary with copper wire and 690V secondary with aluminium strip.

Table 5-2. Bill of Materials and Labour for 2000 kVA M4 in a Cruciform Oval Stack

Material item	Type	Quantity	Each	Total
Core material*	M4 Grain-Oriented Silicon Stee	3,007	€ 1.72	€ 5,172
Primary Winding*	Copper wire (kg)	551	€ 4.42	€ 2,435
Secondary Winding*	Aluminium strip (kg)	191	€ 2.87	€ 547
Winding form & insulation*	Paper with diamond adhesive	55	€ 2.79	€ 153
Coolant / Dielectric	Mineral oil (litres)	2,210	€ 1.00	€ 2,210
Tank and Radiator		1	€ 1,000	€ 1,000
High Voltage Bushing	24kV 250A plug, EN50180	3	€ 50.00	€ 150
Low Voltage Bushing	3150A clamped bushings	4	€ 50.00	€ 200
Hardware and Clamps	misc. & nameplate		€ 121.00	€ 121
Scrap factor (applies to items with * above)			1.00%	€ 83
		Total Material Cost		€ 12,071
Labour item	**Description**	**Hours**	**€/hr**	**Total**
Lead Dressing	Prepare leads after winding	1.00	€ 60.00	€ 60
Handling and Slitting	Working with core steel	2.08	€ 60.00	€ 125
Winding the Primary	Varies with N turns	6.87	€ 60.00	€ 412
Winding the Secondary	Varies with N turns	1.14	€ 60.00	€ 68
Inspection	Quality assurance check	0.20	€ 60.00	€ 12
Baking Coils	Remove air/moisture	0.15	€ 60.00	€ 9
Cutting, Forming, and Annealing	Core steel, varies with grade	1.59	€ 60.00	€ 96
Core Assembly	Assemble around coils, varies	4.41	€ 60.00	€ 265
Tanking and Final Assembly	Attach radiator, pull vaccuum	1.80	€ 60.00	€ 108
Preliminary Test on Windings	Check turns ratio, resistance	0.15	€ 60.00	€ 9
Final Test	Assembled unit test	0.25	€ 60.00	€ 15
Packing and Pallet Loading	Clamping, wrapping and other s	3.00	€ 60.00	€ 180
Marking and Miscellaneous	Labelling bushings, etc.	0.75	€ 60.00	€ 45
		Total Labour Cost		€ 1,404
Manufacturing Cost (Total Material & Total Labour)				€ 13,475
Factory Overhead (Applied to Material Costs Only)		12.5%		€ 1,509
Non-production Cost Markup		25%		€ 3,746
Manufacturer Selling Price				€ 18,729

5.2 BOM for 2000 kVA SA1 in a Wound Core Configuration

The following table provides the bill of materials that was calculated from the OPS design details report (see Annex C). This bill of materials uses the raw material prices given in section 2.2 of this report, which are derived from the draft Preparatory Study. These materials are then marked up at the bottom of the table to allow for factory overheads and non-production mark-ups (see section 2.2 of this report). The sum of the raw material costs, labour costs and mark-ups totals to the manufacturer's selling price. This table provides the bill of materials for 2000 kVA transformer with amorphous material, built in a wound core configuration. This transformer has a 24kV primary with copper wire and 690V secondary with aluminium strip.

Table 5-3. Bill of Materials and Labour for 2000 kVA Amorphous Wound Core

Material item	Type	Quantity	Each	Total
Core material*	Amorphous Material	3,469	€ 3.00	€ 10,406
Primary Winding*	Copper (kg)	813	€ 4.42	€ 3,593
Secondary Winding*	Aluminium strip (kg)	236	€ 2.87	€ 679
Winding form & insulation*	Paper with diamond adhesive	74	€ 2.79	€ 206
Coolant / Dielectric	Mineral oil (litres)	2,353	€ 1.00	€ 2,353
Tank and Radiator		1	€ 1,500	€ 1,500
High Voltage Bushing	24kV 250A plug, EN50180	3	€ 50.00	€ 150
Low Voltage Bushing	3150A clamped bushings	4	€ 50.00	€ 200
Hardware and Clamps	misc. & nameplate		€ 121.00	€ 121
Scrap factor (applies to items with * above)			1.00%	€ 149
		Total Material Cost		€ 19,357
Labour item	**Description**	**Hours**	**€/hr**	**Total**
Lead Dressing	Prepare leads after winding	1.00	€ 60.00	€ 60
Handling and Slitting	Working with core steel	3.72	€ 60.00	€ 223
Winding the Primary	Varies with N turns	5.42	€ 60.00	€ 325
Winding the Secondary	Varies with N turns	0.90	€ 60.00	€ 54
Inspection	Quality assurance check	0.20	€ 60.00	€ 12
Baking Coils	Remove air/moisture	0.15	€ 60.00	€ 9
Core Assembly	Assemble around coils, varies	5.09	€ 60.00	€ 305
Tanking and Final Assembly	Attach radiator, pull vaccuum	1.80	€ 60.00	€ 108
Preliminary Test on Windings	Check turns ratio, resistance	0.15	€ 60.00	€ 9
Final Test	Assembled unit test	0.25	€ 60.00	€ 15
Packing and Pallet Loading	Clamping, wrapping and other s	3.00	€ 60.00	€ 180
Marking and Miscellaneous	Labelling bushings, etc.	0.75	€ 60.00	€ 45
		Total Labour Cost		€ 1,346
Manufacturing Cost (Total Material & Total Labour)				€ 20,703
Factory Overhead (Applied to Material Costs Only)		12.5%		€ 2,420
Non-production Cost Markup		25%		€ 5,781
Manufacturer Selling Price				€ 28,903

Annex A. 400 kVA Designs

All units presented below are metric – weight (kg), wire length (m), areas (cm2), others (mm).

400kVA, 50Hz 3-phase oil-immersed, M4 core steel, copper primary, aluminium secondary

```
               OPTIMIZED PROGRAM SERVICE

                    CLEVELAND OHIO             101800

                        2010- 8-20    14:49:20

 DESIGN ID  400 kva Cruc Oval M4 Eff2

 STRIP CRUC    3-PHASE TYPE TRANSFORMER

 FREQUENCY    50.0             KVA RATING    400.13 @ 100.00% DUTY CYCLE

 CORE  160.000" CRUC  STACK  200.000         GRADE M 4    THICKNESS .2794

 WINDOW:   210.000 X  520.000     EFF. AREA    271.983   WEIGHT   698.158

 WNDG FORM: 170.008 X  260.008 ENDS  85.004 RAD.   1.500 TK.  508.000 LG.

                          COIL SPECIFICATIONS
                          -------------------

 WNDG             WIRE              LENGTH    MEAN TURNS   MARGIN      WT
---------------------------------------------------------------------------
 S1         1.100X 460.000    AL      22.99      0.88    20.000      31.429
 P1   1X 1 DIAM  2.50000 RD H CU    1471.85      1.13    20.000      64.227

 NUMBER OF COILS  3               TOTAL BARE CONDUCTOR WEIGHT    286.969

 WNDG  TURNS  LO TAP  HI TAP  LAYRS   T/L   LAYR INS   SEC. INS    BUILD
---------------------------------------------------------------------------
 S1      26.0                 26      1.0  1( 0.1801) 12( 0.1801)  38.104
 P1    1238.0  1176.1  1299.9  8    181.0  6( 0.1270)  1( 0.0000)  30.415

                                              TOTAL BUILD(%)  78.27

 WNDG              TAPS: TURNS( VOLTS)
---------------------------------------------------------------------------
 P1    1207.1( 10725.00)  1268.9( 11275.00)


 WNDG    INTERNAL DUCTS(100.00) %EFF  EXTERNAL DUCTS(100.00) %EFF
-------------------------------------------------------------------
 S1      1  5.000 X  5.000      FULL
 P1      1  5.000 X  5.000      FULL        5.000 X  5.000      FULL


 WNDG     INTERNAL DUCT LOCATIONS
--------------------------------------------------------------------
 S1  13-14;
 P1   4- 5;
```

```
                        ELECTRICAL ANALYSIS
                        -------------------

    FULL-LOAD    TAP VOLTS       TEST    LOAD    RESIST.  CURRNT
WNDG   VOLTS    LOW       HIGH     KV   CURRENT    @20 C.    DENS.  %REG
---------------------------------------------------------------------------
P1   11000.00 D   10450.00 11550.00 30.0   12.278     5.16970    2.50
S1     228.25 W     231.02 NLV       4.0  577.350     0.00129    1.14  1.2


                F.L.       N.L.   DESTRUCTION FACTOR         1.180
FLUX DENS.       1.460      1.471  LEAKAGE INDUCTANCE MHYS  119.094
CORE LOSS      599.284    609.930  POWER FACTOR               1.000
COIL LOSS     4712.703      0.027  IMPEDANCE %                4.32
EXCIT. VA     1237.595   1264.557  EFFICIENCY %              98.69
EXCIT. CURR.     0.038      0.038  TANK OIL       440.07   LT.
                                   OIL WEIGHT     396.06   Kg.

AMBIENT TEMP.    20.00                NOMINAL LENGTH     1110.000
TEMP.RISE        65.00                NOMINAL  DEPTH      422.111
OPERATING TEMP.  85.00                NOMINAL HEIGHT      840.000


     CRUCIFORM PLATE WIDTHS

       W1    W2    W3
   160.00  140.00  110.00

     STACK HEIGHTS

       H1    H2    H3
    90.00   33.00   22.00

     RESULTANT GROSS AREA:         284.800

              S1  P1
  GRADIENT:     7.4 12.0
  AVG. OIL RISE:    50.
  TOP  OIL RISE:    76.0

SHAPE   TOTAL COOLING AREA    TANK AREA   RAD. AREA     RAD. OIL/ LT. TYPE
----------------------------------------------------------------------------
RECTG.    79823.781         35579.941    44243.840         28.092      C
                                                 2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla

TANK DIMENSIONS
-----------------------
 LENGTH     =   1160.000
 DEPTH      =    472.111
 OIL HEIGHT =   1090.000

        2
 COND. I R LOSS          =   4421.3218
 COND. EDDY CURRENT LOSS =     26.1016
 OTHER STRAY LOSS        =    265.2793
 K VALUE                 =      1.0000
 % LOSS                  =      6.0000
```

```
  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1     0.00508   0.00326


                            o
AT REFERENCE TEMP.      85.0
----------------------------
COIL LOSS   =  4712.798
IMPEDANCE % =     4.319


                                               2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
```

400kVA, 50Hz 3-phase oil-immersed, amorphous material, copper primary, aluminium secondary

```
                        OPTIMIZED PROGRAM SERVICE

                     CLEVELAND OHIO             101800

                         2010- 8-21    12:13: 7

DESIGN ID  400kva5leggedDGSA1EFF10

DG-CORE       3-PHASE TYPE TRANSFORMER  5 LEG

FREQUENCY    50.0             KVA RATING    400.16 @ 100.00% DUTY CYCLE

CORE DG-SA1                         2605-SA1        THICKNESS .0254

  D: 213.000 C:  90.000 B: 240.000 A: 600.000  EFF. AREA       322.06
  D: 213.000 C:  90.000 B: 120.000 A: 600.000  WEIGHT          865.016

WNDG FORM: INS. DIM.  227.000 X  190.000 THICKNESS  1.500 LENGTH  588.000

                         COIL SPECIFICATIONS
                         -------------------

WNDG             WIRE              LENGTH    MEAN TURNS   MARGIN      WT
---------------------------------------------------------------------------
S1         1.200X 540.000    AL       23.35      0.97    20.000      40.883
P1   1X 1 DIAM  3.20000 RD H CU    1565.33      1.30    20.000     111.914

NUMBER OF COILS  3                TOTAL BARE CONDUCTOR WEIGHT    458.392

WNDG  TURNS   LO TAP  HI TAP  LAYRS   T/L   LAYR INS   SEC. INS    BUILD
---------------------------------------------------------------------------
S1      24.0                  24      1.0  1( 0.1801) 12( 0.1801)  37.940
P1    1143.0  1085.8  1200.2  8     155.0  7( 0.1806)  1( 0.0000)  46.274

                                                TOTAL BUILD(%)  77.40

WNDG               TAPS: TURNS( VOLTS)
---------------------------------------------------------------------------
P1    1114.4( 10725.00)  1171.6( 11275.00)


WNDG    INTERNAL DUCTS(100.00) %EFF  EXTERNAL DUCTS(100.00) %EFF
-------------------------------------------------------------------
S1      1  5.000 X  5.000      FULL
P1      2  5.000 X  5.000      FULL        5.000 X  5.000      FULL


WNDG     INTERNAL DUCT LOCATIONS
--------------------------------------------------------------------
S1  12-13;
P1   3- 4; 6- 7;
```

```
                      ELECTRICAL ANALYSIS
                      -------------------

    FULL-LOAD    TAP VOLTS       TEST    LOAD    RESIST.  CURRNT
WNDG   VOLTS    LOW       HIGH     KV   CURRENT   @20 C.    DENS.  %REG
---------------------------------------------------------------------------
P1   11000.00 D   10450.00 11550.00 30.0   12.228     3.35574    1.52
S1     228.93 W     230.97 NLV      10.0  577.500     0.00102    0.89  0.9


                 F.L.       N.L.   DESTRUCTION FACTOR         1.120
FLUX DENS.       1.338      1.345  LEAKAGE INDUCTANCE MHYS  120.126
CORE LOSS      219.203    221.843  POWER FACTOR               1.000
COIL LOSS     3323.882      0.071  IMPEDANCE %                4.27
EXCIT. VA     2472.216   2501.994  EFFICIENCY %              99.12
EXCIT. CURR.     0.075      0.076  TANK OIL       598.07   LT.
                                   OIL WEIGHT     538.26   Kg.

AMBIENT TEMP.    20.00                NOMINAL LENGTH     1455.000
TEMP.RISE        65.00                NOMINAL  DEPTH      477.000
OPERATING TEMP.  85.00                NOMINAL HEIGHT      802.500

               S1  P1
  GRADIENT:     4.3  6.4
  AVG. OIL RISE:    56.
  TOP  OIL RISE:    76.2

SHAPE   TOTAL COOLING AREA    TANK AREA   RAD. AREA     RAD. OIL/ LT. TYPE
---------------------------------------------------------------------------
RECTG.    47649.148         41984.141     5665.004          3.597      C
                                                 2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
TANK DIMENSIONS
------------------------
 LENGTH     =   1467.500
 DEPTH      =    527.000
 OIL HEIGHT =   1052.500

        2
 COND. I R LOSS          =   3090.3191
 COND. EDDY CURRENT LOSS =     48.1437
 OTHER STRAY LOSS        =    185.4191
 K VALUE                 =      1.0000
 % LOSS                  =      6.0000


  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1     0.11405   0.10643

                            o
AT REFERENCE TEMP.      85.0
----------------------------
COIL LOSS   =  3323.942
IMPEDANCE % =     4.266

                                                 2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
```

Annex B. 1000 kVA Designs

All units presented below are metric – weight (kg), wire length (m), areas (cm2), others (mm).

1000kVA, 50Hz 3-phase oil-immersed, M2 core steel, copper primary, aluminium secondary

```
                       OPTIMIZED PROGRAM SERVICE

                    CLEVELAND OHIO            101800

                        2010- 8-11    15:39:23

DESIGN ID  1000 kva Cruc Oval M2 SI Units

STRIP CRUC    3-PHASE TYPE TRANSFORMER

FREQUENCY    50.0             MVA RATING      1.00 @ 100.00% DUTY CYCLE

CORE  180.000" CRUC  STACK  266.000         GRADE M 2    THICKNESS .1778

WINDOW:   280.000 X  730.000     EFF. AREA    428.459   WEIGHT  1436.964

WNDG FORM: 190.008 X  320.008 ENDS  95.004 RAD.   2.000 TK.  718.000 LG.

                         COIL SPECIFICATIONS
                         -------------------

WNDG             WIRE              LENGTH    MEAN TURNS   MARGIN      WT
---------------------------------------------------------------------------
S1          1.500X 670.000    AL      18.36      1.08    22.000      49.864
P1          2.200X   5.600    CU    1211.77      1.42    22.000     126.881

NUMBER OF COILS  3                TOTAL BARE CONDUCTOR WEIGHT    530.236

WNDG  TURNS   LO TAP  HI TAP  LAYRS   T/L   LAYR INS   SEC. INS    BUILD
---------------------------------------------------------------------------
S1      17.0                  17      1.0  1( 0.1801) 12( 0.1801)  44.384
P1     810.0   769.5   850.5  8    108.0  5( 0.1801)  1( 0.0000)  41.731

                                              TOTAL BUILD(%)  78.06

WNDG               TAPS: TURNS( VOLTS)
---------------------------------------------------------------------------
P1     789.8( 10725.00)   830.2( 11275.00)


WNDG    INTERNAL DUCTS(100.00) %EFF  EXTERNAL DUCTS(100.00) %EFF
-------------------------------------------------------------------
S1      2  8.000 X  8.000      FULL
P1      2  8.000 X  8.000      FULL   2    7.000 X  7.000      FULL


WNDG     INTERNAL DUCT LOCATIONS
--------------------------------------------------------------------
S1   6- 7;14-15;
P1   3- 4; 6- 7;

DUCT UNDER BARRIER    7.0000
DUCT OVER  BARRIER    7.0000
```

```
                        ELECTRICAL ANALYSIS
                        -------------------

    FULL-LOAD    TAP VOLTS       TEST    LOAD    RESIST.  CURRNT
WNDG   VOLTS    LOW       HIGH     KV   CURRENT   @20 C.    DENS.  %REG
---------------------------------------------------------------------------
P1   11000.00 D   10450.00 11550.00 30.0   30.642     1.77379    2.60
S1     228.12 W     230.86 NLV       4.0 1444.000     0.00052    1.44  1.2


                 F.L.       N.L.   DESTRUCTION FACTOR         1.180
FLUX DENS.       1.416      1.427  LEAKAGE INDUCTANCE MHYS   67.433
CORE LOSS      919.899    936.369  POWER FACTOR               1.000
COIL LOSS    10855.021      0.029  IMPEDANCE %                5.99
EXCIT. VA     2177.346   2226.578  EFFICIENCY %              98.84
EXCIT. CURR.     0.066      0.067  TANK OIL       871.39   LT.
                                   OIL WEIGHT     784.25   Kg.

AMBIENT TEMP.    20.00                NOMINAL LENGTH     1380.000
TEMP.RISE        65.00                NOMINAL  DEPTH      541.096
OPERATING TEMP.  85.00                NOMINAL HEIGHT     1090.000


     CRUCIFORM PLATE WIDTHS

       W1     W2     W3     W4
   180.00  170.00  150.00  130.00

     STACK HEIGHTS

       H1     H2     H3     H4
   130.00   31.00   21.00   16.00

     RESULTANT GROSS AREA:         444.000

                S1  P1
  GRADIENT:      6.0 11.2
  AVG. OIL RISE:    52.
  TOP  OIL RISE:    85.0

SHAPE   TOTAL COOLING AREA    TANK AREA   RAD. AREA     RAD. OIL/ LT. TYPE
----------------------------------------------------------------------------
RECTG.   168969.375         56186.371  112783.016         71.609      C
                                                 2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
TANK DIMENSIONS
------------------------
 LENGTH     =   1430.000
 DEPTH      =    591.096
 OIL HEIGHT =   1390.000

        2
 COND. I R LOSS          =  10063.7256
 COND. EDDY CURRENT LOSS =     86.8354
 OTHER STRAY LOSS        =    704.4608
 K VALUE                 =      1.0000
 % LOSS                  =      7.0000
```

```
  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1     0.11430   2.08927
```

```
                            o
AT REFERENCE TEMP.      85.0
----------------------------
COIL LOSS   = 10855.215
IMPEDANCE % =     5.986
```

```
                                               2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
```

1000kVA, 50Hz 3-phase oil-immersed, amorphous core, copper primary, aluminium secondary

```
                        OPTIMIZED PROGRAM SERVICE

                      CLEVELAND OHIO             101800

                          2010- 8-17    14:36:59

DESIGN ID  1mva 5-leg WoundCore Eff9

DG-CORE       3-PHASE TYPE TRANSFORMER  5 LEG

FREQUENCY    50.0             MVA RATING      1.00 @ 100.00% DUTY CYCLE

CORE DG-SA1 2(4Core Sets Side By SIde)   2605-SA1        THICKNESS .0254

  D: 416.000 C:  70.000 B: 290.000 A: 860.000  EFF. AREA       489.22
  D: 416.000 C:  70.000 B: 145.000 A: 860.000  WEIGHT         1693.465

WNDG FORM: INS. DIM.  456.000 X  154.000 THICKNESS  2.000 LENGTH  848.000

                            COIL SPECIFICATIONS
                            -------------------

WNDG             WIRE              LENGTH    MEAN TURNS   MARGIN      WT
---------------------------------------------------------------------------
S1   1X 2( 2.200X 400.000)   AL      22.71      1.42     22.000     107.925
P1         3.000X   7.000    CU    1482.94      1.85     22.000     269.712

NUMBER OF COILS  3                TOTAL BARE CONDUCTOR WEIGHT   1132.911

WNDG  TURNS   LO TAP  HI TAP  LAYRS   T/L   LAYR INS   SEC. INS    BUILD
---------------------------------------------------------------------------
S1      16.0                  16      1.0  1( 0.1801) 12( 0.1801)  51.900
P1     762.0   723.9   800.1  8     104.0  5( 0.1801)  1( 0.0000)  39.132

                                              TOTAL BUILD(%)  76.68

WNDG               TAPS: TURNS( VOLTS)
---------------------------------------------------------------------------
P1     743.0( 10725.00)   781.0( 11275.00)


WNDG    INTERNAL DUCTS(100.00) %EFF  EXTERNAL DUCTS(100.00) %EFF
-------------------------------------------------------------------
S1       2  7.000 X  7.000      FULL
P1       1  7.000 X  7.000      FULL   2    8.000 X  8.000      FULL


WNDG     INTERNAL DUCT LOCATIONS
--------------------------------------------------------------------
S1   5- 6;10-11;
P1   4- 5;

DUCT UNDER BARRIER    8.0000
DUCT OVER  BARRIER    8.0000
```

```
                     ELECTRICAL ANALYSIS
                     -------------------

    FULL-LOAD    TAP VOLTS       TEST    LOAD    RESIST.  CURRNT
WNDG   VOLTS    LOW       HIGH     KV   CURRENT   @20 C.    DENS.  %REG
---------------------------------------------------------------------------
P1   11000.00 D   10450.00 11550.00 30.0   30.554     1.24971    1.49
S1     228.85 W     230.97 NLV       4.0 1444.000     0.00037    0.82  0.9


                 F.L.       N.L.   DESTRUCTION FACTOR         1.120
FLUX DENS.       1.320      1.328  LEAKAGE INDUCTANCE MHYS   69.629
CORE LOSS      416.560    422.202  POWER FACTOR               1.000
COIL LOSS     7788.828      0.097  IMPEDANCE %                6.12
EXCIT. VA     4698.045   4761.674  EFFICIENCY %              99.19
EXCIT. CURR.     0.142      0.144  TANK OIL      1092.08   LT.
                                   OIL WEIGHT     982.88   Kg.

AMBIENT TEMP.    20.00                NOMINAL LENGTH     1451.000
TEMP.RISE        65.00                NOMINAL  DEPTH      762.000
OPERATING TEMP.  85.00                NOMINAL HEIGHT     1017.500

               S1  P1
  GRADIENT:     2.7  7.8
  AVG. OIL RISE:    56.
  TOP  OIL RISE:    89.6

SHAPE   TOTAL COOLING AREA    TANK AREA   RAD. AREA     RAD. OIL/ LT. TYPE
----------------------------------------------------------------------------
RECTG.   109448.328         59959.312    49489.012         31.422      C
                                                     2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
TANK DIMENSIONS
------------------------
 LENGTH     =   1463.500
 DEPTH      =    812.000
 OIL HEIGHT =   1317.500

        2
 COND. I R LOSS          =   7075.9712
 COND. EDDY CURRENT LOSS =    217.5384
 OTHER STRAY LOSS        =    495.3180
 K VALUE                 =      1.0000
 % LOSS                  =      7.0000


  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1     0.11430   0.19625

                             o
AT REFERENCE TEMP.      85.0
----------------------------
COIL LOSS   =  7789.070
IMPEDANCE % =     6.117
```

Annex C. 2000 kVA Designs

All units presented below are metric – weight (kg), wire length (m), areas (cm2), others (mm).

2000kVA, 50Hz 3-phase oil-immersed, M4 core steel, copper primary, aluminium secondary

```
                         OPTIMIZED PROGRAM SERVICE

                      CLEVELAND OHIO             101800

                          2010- 8-20     8:46:45

DESIGN ID  2mvaM4CrucOvalEff1

STRIP CRUC    3-PHASE TYPE TRANSFORMER

FREQUENCY    50.0             MVA RATING      2.00 @ 100.00% DUTY CYCLE

CORE  210.000" CRUC  STACK  391.000         GRADE M 4    THICKNESS .2794

WINDOW:   350.000 X  960.000     EFF. AREA    710.495   WEIGHT  3007.062

WNDG FORM: 220.008 X  445.008 ENDS 110.004 RAD.   2.540 TK.  940.000 LG.

                           COIL SPECIFICATIONS
                           -------------------

WNDG             WIRE              LENGTH    MEAN TURNS   MARGIN      WT
---------------------------------------------------------------------------
S1   1X 2( 1.100X 420.000)   AL      25.45      1.34    30.000      63.538
P1         2.000X   5.000    CU    2183.67      1.82    35.000     183.624

NUMBER OF COILS  3               TOTAL BARE CONDUCTOR WEIGHT    741.485

WNDG  TURNS  LO TAP  HI TAP  LAYRS   T/L   LAYR INS   SEC. INS    BUILD
---------------------------------------------------------------------------
S1      19.0                 19      1.0  1( 0.2540) 16( 0.2540)  55.473
P1    1145.0  1087.8  1202.2  8     76.0  5( 0.1801)  1( 0.0000)  43.319
                            TURNS/LAYER/SECTION = 76.0

                                                TOTAL BUILD(%)  74.51

WNDG               TAPS: TURNS( VOLTS)
---------------------------------------------------------------------------
P1    1116.4( 23400.00)  1173.6( 24600.00)


                          SECTION  INFORMATION
                          -----------------

WNDG   SECTION   WIDTH    VOLTS/SECTION      SPACE
-------------------------------------------------------
P1        2     415.000    12600.000         40.000


WNDG    INTERNAL DUCTS(100.00) %EFF  EXTERNAL DUCTS(100.00) %EFF
-------------------------------------------------------------------
S1      3 10.000 X 10.000      FULL
P1      2 10.000 X 10.000      FULL   2   10.000 X 10.000      FULL
```

```
 WNDG     INTERNAL DUCT LOCATIONS
--------------------------------------------------------------------
 S1   4- 5;10-11;16-17;

 P1   3- 4; 6- 7;

 DUCT UNDER BARRIER   10.0000
 DUCT OVER  BARRIER   10.0000


                         ELECTRICAL ANALYSIS
                         -------------------

     FULL-LOAD    TAP VOLTS       TEST    LOAD    RESIST.  CURRNT
 WNDG   VOLTS    LOW       HIGH     KV   CURRENT   @20 C.    DENS.  %REG
---------------------------------------------------------------------------
 P1   24000.00 D   22800.00 25200.00 50.0   28.080     3.98022    2.97
 S1     393.56 W     398.25 NLV      10.0 1674.000     0.00078    1.81  1.2


                  F.L.       N.L.   DESTRUCTION FACTOR         1.180
 FLUX DENS.       1.318      1.328  LEAKAGE INDUCTANCE MHYS  170.217
 CORE LOSS     2069.574   2103.043  POWER FACTOR               1.000
 COIL LOSS    21402.863      0.039  IMPEDANCE %                6.33
 EXCIT. VA     3682.458   3745.875  EFFICIENCY %              98.84
 EXCIT. CURR.     0.051      0.052  TANK OIL      2041.30   LT.
                                    OIL WEIGHT    1837.17   Kg.

 AMBIENT TEMP.    20.00                NOMINAL LENGTH     1680.000
 TEMP.RISE        65.00                NOMINAL  DEPTH      697.939
 OPERATING TEMP.  85.00                NOMINAL HEIGHT     1380.000


      CRUCIFORM PLATE WIDTHS

        W1    W2    W3    W4    W5
    210.00  190.00  170.00  140.00  110.00

      STACK HEIGHTS

        H1    H2    H3    H4    H5
    225.00   31.00   21.00   17.00   14.00

      RESULTANT GROSS AREA:         740.100

                S1  P1
   GRADIENT:    10.3 12.8
   AVG. OIL RISE:    49.
   TOP  OIL RISE:    77.0

 SHAPE   TOTAL COOLING AREA    TANK AREA   RAD. AREA     RAD. OIL/ LT. TYPE
----------------------------------------------------------------------------
 RECTG.   359545.969         94352.391   265193.562        168.379      C
                                                     2
 SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
 TANK DIMENSIONS
 ------------------------
  LENGTH     =   1780.000
  DEPTH      =    797.939
  OIL HEIGHT =   1830.000
```

```
       2
COND. I R LOSS           =  19544.1172
COND. EDDY CURRENT LOSS =     99.7767
OTHER STRAY LOSS        =   1758.9703
K VALUE                 =      1.0000
% LOSS                  =      9.0000



                              o
AT REFERENCE TEMP.      85.0
----------------------------
COIL LOSS   = 21403.119
IMPEDANCE % =     6.332

SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
```

2000kVA, 50Hz 3-phase oil-immersed, amorphous core, copper primary, aluminium secondary

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                        OPTIMIZED PROGRAM SERVICE

                     CLEVELAND OHIO             101800

                         2010- 8-18    10:24:53

DESIGN ID  2000kva5LeggedDGSA1EFF4

DG-CORE       3-PHASE TYPE TRANSFORMER  5 LEG

FREQUENCY    50.0             MVA RATING      2.00 @ 100.00% DUTY CYCLE

CORE DG-SA1 2(4 Core Sets)             2605-SA1        THICKNESS .0254

  D: 428.000 C: 125.000 B: 370.000 A: 850.000  EFF. AREA       898.80
  D: 428.000 C: 125.000 B: 185.000 A: 850.000  WEIGHT         3468.644

WNDG FORM: INS. DIM.  468.000 X  274.000 THICKNESS  2.540 LENGTH  830.000

                         COIL SPECIFICATIONS
                         -------------------

WNDG             WIRE              LENGTH    MEAN TURNS   MARGIN      WT
---------------------------------------------------------------------------
S1   1X 2( 1.500X 385.000)   AL      25.26      1.68    30.000      78.825
P1         2.500X   6.000    CU    2107.82      2.22    35.000     270.949

NUMBER OF COILS  3                TOTAL BARE CONDUCTOR WEIGHT   1049.321

WNDG  TURNS  LO TAP  HI TAP  LAYRS   T/L   LAYR INS   SEC. INS    BUILD
---------------------------------------------------------------------------
S1      15.0                 15      1.0  1( 0.2540) 16( 0.2540)  56.058
P1     904.0   858.8   949.2  9     55.0  5( 0.1801)  1( 0.0000)  60.848
                           TURNS/LAYER/SECTION = 55.0

                                                TOTAL BUILD(%)  77.57

WNDG               TAPS: TURNS( VOLTS)
---------------------------------------------------------------------------
P1     881.4( 23400.00)   926.6( 24600.00)


                        SECTION  INFORMATION
                        ----------------

WNDG   SECTION   WIDTH    VOLTS/SECTION      SPACE
-------------------------------------------------------
P1        2     365.000    12600.000         30.000


WNDG    INTERNAL DUCTS(100.00) %EFF  EXTERNAL DUCTS(100.00) %EFF
-------------------------------------------------------------------
S1      3 10.000 X 10.000      FULL
P1      3 10.000 X 10.000      FULL   2   10.000 X 10.000      FULL
```

```
WNDG     INTERNAL DUCT LOCATIONS
-------------------------------------------------------------------
S1   4- 5; 9-10;14-15;

P1   2- 3; 5- 6; 8- 9;

DUCT UNDER BARRIER   10.0000
DUCT OVER  BARRIER   10.0000


                        ELECTRICAL ANALYSIS
                        -------------------

    FULL-LOAD    TAP VOLTS       TEST    LOAD    RESIST.  CURRNT
WNDG   VOLTS    LOW       HIGH     KV   CURRENT   @20 C.    DENS.  %REG
---------------------------------------------------------------------------
P1   24000.00 D   22800.00 25200.00 90.0   27.981     2.51327    1.94
S1     394.71 W     398.23 NLV      10.0 1674.000     0.00062    1.45  0.9


                 F.L.       N.L.   DESTRUCTION FACTOR         1.120
FLUX DENS.       1.323      1.330  LEAKAGE INDUCTANCE MHYS  162.342
CORE LOSS      856.561    866.747  POWER FACTOR               1.000
COIL LOSS    15056.911      0.170  IMPEDANCE %                5.99
EXCIT. VA     9660.458   9775.346  EFFICIENCY %              99.21
EXCIT. CURR.     0.134      0.136  TANK OIL      2271.95   LT.
                                   OIL WEIGHT    2044.76   Kg.

AMBIENT TEMP.    20.00                NOMINAL LENGTH     2146.000
TEMP.RISE        65.00                NOMINAL  DEPTH      858.000
OPERATING TEMP.  85.00                NOMINAL HEIGHT     1131.250

               S1  P1
  GRADIENT:     6.6  6.5
  AVG. OIL RISE:    54.
  TOP  OIL RISE:    74.8

SHAPE   TOTAL COOLING AREA    TANK AREA   RAD. AREA     RAD. OIL/ LT. TYPE
----------------------------------------------------------------------------
RECTG.   219602.094         91585.500   128016.586         81.282      C
                                                2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
TANK DIMENSIONS
------------------------
 LENGTH     =   2163.500
 DEPTH      =    928.000
 OIL HEIGHT =   1481.250

        2
 COND. I R LOSS          =  13641.3740
 COND. EDDY CURRENT LOSS =    187.8132
 OTHER STRAY LOSS        =   1227.7238
 K VALUE                 =      1.0000
 % LOSS                  =      9.0000

                             o
AT REFERENCE TEMP.      85.0
----------------------------
COIL LOSS   = 15057.076
IMPEDANCE % =     5.985

                                                2
SI UNITS: WEIGHT  Kg -WIRE LENGTH  m -AREAS  Cm -ALL OTHERS  mm -B tesla
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