Exploratory Analysis of the Market Trend of Power Transformers in Mexico for Manufacturing Sector for Exportation

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Abstract. The electric sector continues in constant development, the requirements that the market demands must be included in the design and manufacturing processes of the components that make up the grid, such as the Power Transformers. The objective of the research presented is to know the general characteristics that impact the design and manufacture of transformers in Mexico, for which, four stages were identified as part of the General Methodology, which includes the niche market, the companies that manufacture in Mexico, the volume of exported transformers, as well as the suppliers and raw materials that are necessary for their production. For which a literary research was carried out, also the consultation in secondary sources, field research in a manufacturing company, and analysis of statistical data through the Minitab program, and a comparison of the bill of materials (BOM) of the transformers with the highest export index. All this will allow us to know, influence and improve the design and manufacturing of transformers.

1. Introduction

The electricity sector is one of the fastest growing markets worldwide, factors such as population growth [1] and technological changes have influence the electricity networks [2].

Countries with the highest growth expectations such as China and the United States demand a future high investment in their infrastructure [3]. Are estimated the requirements of electric power in the United States at a consumption of 3,782,151 GWh, distributed in Residential 36.8%, followed by Commercial and Services 35.4%, Industry 22.4%, Farming 0.8%, Transportation 0.2% and Other Sectors 4.5% [4].

To guarantee efficiency in your electricity network and at the lowest possible cost, it is vitally important to include in the purchase and renovation of your infrastructure reliable components, among the most important is the transformer.

The transformer is considered by Hobday [5], as a complex product, among its most outstanding features are its high costs and customized production, which implies a small number of products manufactured with individual characteristics for each customer, which brings as consequently, the generic design requires a review during delivery to the final consumer [6].

The United States has global suppliers that contribute to meet its demand for Power Transformers (TP), among which companies established in Mexico such as GE / PROLEC, IEM, SIEMENS, WEG [3] stand out.
It is important to highlight the importance of this type of companies, given that 80.6% of the products manufactured in Mexico are sent to the United States, of this figure, 0.7% corresponds to the export of electrical transformers, which translates into 243,978 thousand dollars, according to figures reported by the National Institute of Statistics and Geography (INEGI Acronym in Spanish) [7].

Due to the importance of the TP, the general objective of this article is to present the results achieved in the research of the transformer market for the manufacturing sector in Mexico; to know the general and material characteristics of power transformers designed and manufactured for export; through the identification of macroeconomic indicators, microeconomic analysis of the product trend and the Bill of Materials (BOM).

The scope of this article is an exploratory type, carried out in Mexico City, considering the description of the general methodology of literary search, field research in a manufacturing company and the analysis of the findings found; given that, in articles related to the manufacture of transformers and official reports issued by the competent agencies, a characterization of the TP manufactured in Mexico for export has not been issued.

In the general search methodology, we consulted on pages such as: National Consortium for Scientific and Technological Information Resources (CONRiCyT), SPRINGER, IEEE Xplore Digital Library, Electric Power Research, Taylor and Francis, Scopus, ScienceDirect, as well as reports on Organizations like International Energy Agency, OECD, US Department of Energy, The World Economic Forum, and the Mexican Ministry of Energy and Federal Electricity Commission, National Chamber of Electrical Manufactures (CANAME acronym in Spanish), Directory of Transformer Factories in Mexico, and National Institute of Statistics and Geography (INEGI).

2. Research Development
The General research methodology, is supported by the systems approach, where a set of subjects, objects and concepts are conceptualized, which are related to fulfill a common mission, which allows us to identify a macro system with its different stages to the manufacture of a product, where it is located: Manufactured Niche, Manufactured Company, Manufactured Product, Manufacturing Supplier (NCPS) (See Figure 1)

![Figure 1. General Research Methodology](image)

This leads us to conceptualize four stages:
A. Identification of the niche market.
B. Identification of transformer manufacturing companies.
C. Identification of products manufactured for export.
D. Identification of manufacturing suppliers.
A. Identification of the market niche.

The identification of the market niche, we carry out through the literary search in official reports such as International Energy Agency, World Economic Forum, among others, this allowed us to generate an article, in which the main socioeconomic trends of the electricity markets were identified, energy sources, generation and consumption capacity of countries with the greatest growth potential worldwide such as China and the United States [14].

This allowed us to know the expectation of growth in future PT requirements for the United States [3], and consider it as the appropriate target market for exports of transformer manufacturing companies and their components.

B. Identification of manufacturing companies.

For the identification of manufacturing companies in Mexico, we consult reports on pages of organizations such as the National Institute of Statistics and Geography (INEGI) [8], National Chamber of Electrical Manufactures (CANAME) [9], Directory of Transformer Factories in Mexico [10], Federal Electricity Commission (CFE), during the period July 2018 to December 2018. The keywords used: Manufacturing, Manufacturer, Company, Transformers; which allowed identifying related criteria such as Place of establishment and Products Offered.

1. Place of Establishment: The results obtained indicate that 63% are located in the center of the country. (See Figure 2)

![Figure 2. Establishment of Transformer Manufacturers by State](image)

2. Products offered: The results found indicate that the products offered by the manufacturers are: 23 manufacture transformers type Distribution, 4 Distribution and Medium Power, 3 Maintenance Service (Workshops), 1 offers Distribution transformers, Medium Power and Power, and 1 company exports all its manufactured product. (See Figure 6). (The type of Transformer Distribution product, for the purposes of this study, refers to all those with a capacity of less than 10 MVA).
Figure 3. Products offered

C. Identification of products manufactured for export.

For the identification of manufactured products, the stages are required:
C.1 Analysis of sales order records.
C.2 Analysis of the sales trend.
C.3 Exploration of the list of materials, and identification of raw materials.

C.1 Analysis of sales order records.
For this stage, we conducted a field investigation, where we visited the manufacturing company “XYZ” located in the Center of Mexico, which has more than 500 employees, operating for more than 35 years in Mexico, offering products that range from Distribution type (Substation, encapsulated, dry, renewable, pole, with capacities less than 10 MVA), Medium Power and Power Transformers, ranging from 10 MVA to 350 MVA, to know the characteristics of the manufactured TP; for which, the registration of the orders executed during the period from the year 2000 to 2017 was carried out.

Due to the nature of this exploratory study, the collection and processing of the data, existing sources in the current market were considered, as well as some statistical analysis procedures described in the literature [11], considering the review of the orders Registered between 2000 and 2017, where Medium Power and Power Transformers are considered as objects of study, with a capacity of 10 MVA up to 230 MVA.

The total population is limited to 509 orders, where we considered the following seven variables:
1. Destination of the Transformer
2. Type of Client
3. Type of Industry
4. Transformer Capacity (MVA)
5. Transformer Type
6. Single phase - Three phase
7. Voltage Class in High Voltage (KV)

1. Destination of the Transformer: we found that the 95% are exported to United States, the remaining 5% to other countries. (See Figure 4)
2. Type of Client: we found that are five types of clients (See Table 1), of which 54% belong to orders from Municipalities, followed by EPC, and IOUs [13] with 15% each. (See Figure 5)

Table 1. Kind of Client

| Code  | Definition                  |
|-------|----------------------------|
| C&I   | Industrial Client          |
| EPC   | Engineering Product Client |
| IOUs  | Investor Owner Utilities   |
| Municipals | Public Power Utilities    |
| Renewable | Renewable                  |

Figure 4. Exports

Figure 5. Kind of Client
3. Type of Industry: we found that the record of 8 Types of Industries, in which 70% exceeds that required in Utility, followed by Oil-Gas with 13%. (See Figure 6)

![Figure 6. Kind of Industry](image)

4. Capacity (KVA): we found 99 types of capacities, from 10 to 224 MVA; of which, the largest number of orders is 20 MVA, followed by 30 and 25 MVA, which represents 45% of the requested orders. The representation of all types, we made consider a range of them, taking in account the ranges established in accordance with the Regulations established by IEEE for the Table of Preferred Ranges [12] (See Figure 7)

![Figure 7. Capacity MVA](image)

5. Transformer Type: we found that 86% are Substation Type and the rest of other Transformers type. (See Figure 8)
6. Single phase - Three phase: we found that 97% of orders are required with 3 phases and 3% with one. (See Figure 9)

7. Voltage Kind: In this category, kind 138 and 69 KV in High Voltage stand out. (See Figure 10)
C.2 Sales trend analysis.

In the second stage, the analysis of the sales trend is carried out; Table 2 shows the quantities of units sold from the year 2000 to 2017 of kind 138 and 69 KV. It can be seen that, in some years, exports are zero, however, there are other periods in which it increases, this provides an unpredictable variability in demand, so a linear and quadratic trend adjustment is made, which These are the adjustments that can be made with the available data, to observe the behavior over time, as well as a forecast for the next three annual periods.

| Year | Model 69 | Model 138 |
|------|----------|-----------|
| 2000 | 0        | 0         |
| 2001 | 7        | 0         |
| 2002 | 0        | 0         |
| 2003 | 0        | 0         |
| 2004 | 9        | 4         |
| 2005 | 3        | 0         |
| 2006 | 0        | 0         |
| 2007 | 1        | 6         |
| 2008 | 0        | 6         |
| 2009 | 0        | 1         |
| 2010 | 0        | 4         |
| 2011 | 0        | 1         |
| 2012 | 0        | 1         |
| 2013 | 0        | 2         |
| 2014 | 0        | 1         |
| 2015 | 0        | 0         |
| 2016 | 1        | 0         |
We made adjustments to the sales of Model 138 through Minitab, it can be seen that sales are more adjusted to a linear trend, rather than the quadratic one, due to its average absolute percentage error (MAPE), also known as Deviation Percentage Absolute Average, which measures the accuracy of the method for the adjusted construction of time series values in statistics, is less, 59.7404 of the linear versus 71.7487, as shown in Figures 11 and 12, respectively. The forecasts for the following three periods, 1.75, 1.77 and 1.79, show a slight tendency to generate some export, although its slope, whose value is 0.025, is of minimum growth.

For Model 69, is presented the best fit in the quadratic, considering a lower MAPE value (61.7057) than the linear one (73.4477), which are presented in Figures 13 and 14 although the behavior in both is negative, that is to be considered for future planning. In this case, the forecasts do not indicate exports in the next 3 years, which leaves the propensity to manufacture in a position of extreme fragility. The MAD values, referring to the absolute deviation of the mean, and the MSD, the mean square deviation, in both cases, do not have a significant difference considering a 5% error.

![Linear Trend Function](image1)

**Figure 11.** Linear trend analysis graph with three-period forecasts for Class 138

![Quadratic Trend Function](image2)

**Figure 12.** Graph of quadratic trend analysis with three-period forecasts for Class 138
C3. Materials list exploration and identification of raw materials
The exploration of the list of materials and identification of raw materials consisted of comparing the list of materials of three types of medium power transformers, randomly chosen from a population of 26 with characteristics of 20 MVA, Class 138, three phases. We identify the description of the materials listed in each of the chosen models, (See Table 3, 4, 5), among which, we consider both the basic and raw materials; (oriented grain silicon steel, copper conductors, iron, oil, No Load Tap changer (NLTC), Load Tap changer (LTC) and insulations [3, 14]). This allowed us to count an average of 52 pieces or assemblies in each transformer model subdivided into 6 main parts, the Tank, Core Coil and Connections Assemblies (CCCA), Accessories, Nozzles and Connectors, Miscellaneous, and Shipping assemblies. (See Table 6)
| Assembly | Model Standard IEEE 20 MVA Model 138 Kv |
|----------|----------------------------------------|
| **Tank** | Steel A36  
L1500 Straight Radiator  
Butterfly Valve PN10 3  
Stainless Steel Conservator Tank |
| **Assembly Core, Coils and Connections** | Oriented Grain Silicon Steel Core M4  
Low Voltage Cable CTC 0.48 4.9X1.6 90  
High Voltage Cable 0.72mm 6.8X1.9mm T 90  
Round Copper 3/8X3”  
Thermostabilizer Copper Cable 14 3/0 AWG  
Paperboard PHP 3mmX2100mmX3200mm  
Insulating Paper Thermostabilizer 0.254X12  
Densified Wood 60mm  
No Load Tap Charger 550kV/300  
Paperboard Coils Assembly  
Assembly Iron Core |
| **Accessories** | Winding Thermometer  
Thermal plate  
Oil Thermometer  
Oil Gauche 152mm  
Pressure Valve  
Manovacometer  
Inertair Team  
Fan 0.5cv 4.01m³/s  
Control Cabinet  
Wired Pipe List  
Current Transformer 1200/800/300/200:5  
Current Transformer 1000/5A C400 60hz  
Current Transformer 400/5 A C-400 |
| **Bushing and Connectors** | Bushing Driver 650kV 800A  
Rigid Bushing Driver 15kV/900A/110kV  
Bushing Assembly  
Mho Connector |
| **Miscellaneous** | -40° Naftenic Insulation Oil  
Electronic Plug 1 and 2  
Transportation monitor |
| **Shipment** | Treated Wood 2.5X25X250 - 3.8X7.6X250 - 7.6X7.6X250  
1000 Liters Polyethylene Container  
Hard Plastic 1,200X1,050X1,500mm  
Gas Cylinder for High Pressure 9m³ |
| Assembly                        | Model 2                                                                 |
|--------------------------------|-------------------------------------------------------------------------|
| Tank                           | Oriented Grain Silicon Steel Core M4-branched                              |
|                                | Assembly Core, Coils and Connections                                    |
|                                | Low Voltage Regulation Cable CTC 0.6 6.2X1.6 90                            |
|                                | Low Voltage Cable CTC 0.6 4.4X1.6 90                                     |
|                                | High Voltage Cable SRC 22HCC 0.84mm 6.1X2mm T 90                         |
|                                | Thermostabilizer Copper Cable TMA14 500 MCM                              |
|                                | Thermostabilizer Copper Cable TMA14 3/0 AWG                              |
|                                | Paperboard PHP 3mmX2100mmX3200mm                                         |
|                                | Insulating Paper Thermostabilizer 0.254X12                               |
|                                | Densified Wood 60mm                                                      |
|                                | No Load Tap Charger 138kV/538A                                           |
|                                | Load Tap Charger 33 26,4 K                                               |
|                                | 1.2 MVA Reactor                                                          |
|                                | Paperboard Coil Assembly                                                 |
|                                | Assembly Iron Core                                                       |
|                                | Accessories                                                              |
|                                | Windig Thermometer                                                       |
|                                | Thermal Plate                                                            |
|                                | Oil Thermometer                                                          |
|                                | Oil Gauche 152mm                                                         |
|                                | Fan 0.5cv 4.01m9/s                                                       |
|                                | Control Cabinet                                                          |
|                                | Current Transformer 1200/800/300/200:5                                   |
|                                | Current Transformer 1200/800/300/200:5 A C-400                             |
|                                | Current Transformer 400/5A C400 60hz                                    |
|                                | Tension Regulator                                                        |
|                                | Auxiliary Current Transformer                                           |
|                                | Adapter Panel 311X317.5X3mm                                              |
|                                | Wired Pipe List                                                          |
|                                | Transportation Monitor                                                   |
|                                | Miscellaneous                                                            |
|                                | -40° Naftenic Insulation Oil                                             |
|                                | Electronic Plug 1 and 2                                                  |
|                                | Copper Terminal 375mm² 2 12.7mm                                           |
|                                | Copper Terminal 380mm² 32.9X26mm                                         |
|                                | Pipe Assembly 380mm²                                                      |
|                                | Shipment                                                                 |
|                                | Treated Wood 2.5X25X250                                                  |
|                                | 1000 Lts Polyethylene Container                                          |
|                                | Hard Plastic 1,200x1,050x1,500mm                                         |
|                                | 7.6X7.6X250                                                              |

**Table 4.** Model Standard IEEE 20 MVA Model 138Kv
| Assembly                                                  | Model 3                                                                 |
|-----------------------------------------------------------|-------------------------------------------------------------------------|
| **Tank**                                                  |                                                                          |
| Tank                                                     | L2000 Radiator                                                          |
| Assembly, Coils, and Connections                         |                                                                          |
| Oriented Grain Silicon Core 23ZDKH85                     |                                                                          |
| Low Voltage Cable CTC 0.45 4.4X1.6 140                   |                                                                          |
| High Voltage Cable CTC 0.72 7.2X1.8 90                   |                                                                          |
| High Regulation Cable CTC 0.72 7.2X1.8 90               |                                                                          |
| Thermostabilizer Copper Cable TMA14 600 MCM             |                                                                          |
| Thermostabilizer Copper Cable TMA14 1000 MCM            |                                                                          |
| Paperboard PHP 3mmX2100mmX3200mm                        |                                                                          |
| Insulating Paper Thermostabilizer 0.254X12              |                                                                          |
| Densified Wood WOOD 60mm                                 |                                                                          |
| Load Tap Charger LTC 72.5-10 19 W                       |                                                                          |
| Paperboard TX 10mmX2100mmX3200mm                        |                                                                          |
| Assembly Iron Core                                       |                                                                          |
| Steel Core M4 for Reactor                               |                                                                          |
| **Accessories**                                          |                                                                          |
| Oil Thermometer                                          | Relay Locker                                                            |
| Thermal Plate                                            | Relay                                                                   |
| Oil Thermometer                                          | Rubber Bag 1X1140X2620mm                                                |
| Scada Electronic Level                                   | Dehydrator                                                              |
| Pressure Valve C-5M                                      | Control Cabinet                                                         |
| Pressure Relay                                           | Wired Pipe List                                                         |
| Current Transformer 1200/800/300/200:5                   |                                                                          |
| Current Transformer 1500/5A C400 60hz                    |                                                                          |
| Backup Control M-0329B BECK (1000400)                    |                                                                          |
| Electric Regulator                                       |                                                                          |
| Current Loop Internal Beck                               |                                                                          |
| **Bushing Connectors and Mho Connector**                 |                                                                          |
| Bushing 1200 a                                           | Bushing Assembly                                                       |
| Rigid Bushing Driver 15KV/3000A/110KV                    |                                                                          |
| Rigid Bushing Driver 15KV/1315A/110KV, 119T              |                                                                          |
| Mho Connector                                            |                                                                          |
| **Miscellaneous**                                        |                                                                          |
| FR3 Envirotemp Insulation Oil                            |                                                                         |
| Alarm Annunciator                                        |                                                                         |
| Transformer Control                                      |                                                                         |
| Transportation Monitor                                   |                                                                         |
| Copper Terminal 375mm² 2F12.7mm                           |                                                                         |
| Pipe Assembly 380mm²                                     |                                                                         |
| **Shipment**                                             |                                                                         |
| Treated Wood 2.5X25X250                                   |                                                                         |
| 1000 Lts Polyethylene Container                          |                                                                         |
| Hard Plastic 1,200X1,050X1,500mm                         |                                                                         |
| **Table 5. Model Standard IEEE 20 MVA Model 138 Kv**     |                                                                         |
Table 6. Assembly number

| Assembly                        | Assembly - Pieces Number |
|--------------------------------|--------------------------|
|                                | Model 1 | Model 2 | Model 3 |
| Tank                            | 4       | 4       | 4       |
| Assembly Core, Coils and Connections | 11      | 14      | 13      |
| Accessories                     | 13      | 17      | 23      |
| Bushings and Connectors         | 4       | 4       | 5       |
| Miscellaneous                   | 4       | 7       | 10      |
| Shipment                        | 6       | 7       | 7       |
| **Total**                       | **42**  | **53**  | **62**  |

After counting the assemblies in each model, those considered critical were identified, this led us to verify that the greatest amount of raw materials are in the CCCA with 50% in Model 1, 50% in Model 2 and 46% in Model 3. (See Table 7)

Table 7. Raw Material

| Assembly                        | Raw Material |
|--------------------------------|--------------|
|                                | Model 1 | Model 2 | Model 3 |
| Tank                            | 3       | 3       | 3       |
| Assembly Core, Coils and Connections | 10      | 12      | 11      |
| Accessories                     | 1       | 1       | 0       |
| Bushings and Connectors         | 3       | 3       | 4       |
| Miscellaneous                   | 1       | 3       | 3       |
| Shipment                        | 3       | 3       | 3       |
| **Total**                       | **21**  | **25**  | **24**  |

The exploratory study carried out, allows us to observe that the CCCA, composed of critical materials such as oriented grain silicon steel, Insulations, Copper, No Load Tap changer (NLTC), Load Tap changer (LTC), represents the highest percentage in the structure of the materials within the list of materials of the transformer models revised.

D. Identification of manufacturing suppliers.

For the identification of the suppliers of raw materials, we carried out the literary review of official reports issued by government agencies, we found that the US Department of Energy considers as official suppliers of silicon steel countries such as China, Czech Republic, Germany, Japan, Korea, Poland and Russia. [3, 15]

Mexico imports Insulations and Load Tap Changers from the United States and Germany [14], which represents an approximate lead-time of 8 months.

The lack of suppliers in Mexico, of the critical materials for the manufacture of the PT, is a factor that also significantly affect the cost of its manufacture. Therefore, part of the suggestions of the exploratory research carried out is to contextualize the importance of manufacturing companies of this type of materials in Mexico, given the future growth in the US electricity market.

3. Conclusions and Future work

The electricity sector in the United States will continue to grow [14], the result obtained from exploratory research, allows us to infer that, in the coming years, it will increase the export of power transformers for generation and transmission, 20 MVA Class 138 KV for the United States, manufactured in Mexico.
The results obtained from the trend analysis of the time series, sales for Class 69 K\textsuperscript{V}, observe a decrease, however, they could be considered for future sales, when the United States government would authorize investments in the Transmission sector.

The growth of the electricity sector and exports to the United States, offer the opportunity to open new distributors or manufacturers of critical materials in Mexico, and thereby reduce imports and manufacturing costs. The realization of a structured questionnaire or interview, to know the conditions by which the three models of transformers analyzed contain differences between their materials, is part of a future research that will allow a better analysis of the raw materials.

The exploratory research carried out, through the systems approach, allows generating a methodology that contributes to the identification of the most outstanding variables for the decision making of companies that intend to export different products manufactured in Mexico.

**Acknowledgements**
The authors are grateful for the support to the company “Transformers XYZ”, for the facilities provided for conducting the research.

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