Evolution of MV Extruded Cable Designs Used in the US from 1996 to 2014

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ABSTRACT

Developments in cable designs have always been of great interest to utilities and manufacturers alike. In 2003, Joe Dudas, with support from utility bodies (AEIC & NRECA), performed several surveys to establish the industry trends in medium voltage (MV) extruded cable usage. The results of these surveys proved to be very useful to utilities and manufacturers in understanding current. In 2016, the authors undertook a utility survey on cable, materials, and accessories to all interested parties. This study covered the experiences of >50 different utilities. The analyses within the 2016 study enabled the authors to follow the methodologies of the previous studies of Dudas et al, to provide perspectives on present day cable and accessory usage in the US.

KEYWORDS

Design, MV, Extruded Cable Systems

INTRODUCTION

Developments in cable designs have always been of great interest to utilities and manufacturers alike ([1] - [6]). However, when there are many potential design choices available, it can be difficult to determine underlying trends and developments. In 2003, Joe Dudas, with support from utility bodies (AEIC & NRECA), performed several surveys to establish the industry trends in medium voltage (MV) extruded cable usage. The results of these surveys proved to be very useful to utilities and manufacturers in understanding current trends in the use of different insulation types, cable designs, and installation practices of particular use is the fact that the 2003 survey was the last of a series starting back in 1992. However, due to the development of new cable standards and designs and the evolution of replacement / maintenance strategies, these survey results are likely no longer accurate. The authors estimate that there are approximately 9 different generations of designs currently installed on utility systems.

In 2016, the authors undertook a utility survey into the cable, materials, and accessories used by all interested parties. This study covered the experiences of >50 different utilities. The analyses within the 2016 study enabled the authors to follow the methodologies of the previous studies of Dudas et al, to provide perspectives on present day cable and accessory usage in the US, including:

- metal used for the conductor,
- conductor shield type (conventional or supersmooth),
- conductor size,
- insulation type (WTRXLPE or EPR),
- insulation wall thickness, and
- accessory types (premoulded, heat shrink, or cold shrink)
- etc

As this work follows very closely the methodology used by Dudas and his colleagues, in some cases it is possible to extend the trends developed by these earlier studies.

This study also collected information on the important factors considered by utilities when selecting a cable for use within the distribution system.

APPROACH

Previous Studies

Prior work in this area was performed by Joe Dudas and supported by AEIC and NRECA to establish industry trends in medium voltage cable usage (15 kV to 35 kV). His work started in 1993 and updated approximately every 5 years until 2003. Interestingly, essentially identical questions were asked in each of the surveys allowing trends to be derived. The results were reported separately for investor owned utilities (IOU) and cooperatives (co-ops). The information collated was useful to utilities and manufacturers in understanding technical specification trends and installation practices. The last survey was conducted in 2003. With technology evolution and changes in utility operations, the results from the 2003 survey are likely outdated.

This Study

This study seeks to review and analyze the published data from the previous surveys and re-establish the survey to determine today's usage trends. Previous surveys focused on cables. A number of issues with accessories are also worth exploring. This study covers cable designs, accessory designs, and installation practices. Investor owned utilities and co-op data are reported together in this study. The results from this study provides a 2014-2015 benchmark on utility cable and accessory specifications and extends the 10-year technical specification trend developed by Dudas to a 20-year trend. It also provides updates on current practice/trends in cable replacement and rejuvenation and helps collate experiences/new issues with our aging cable system population. The findings from this work will be shared with interested parties and help guide necessary changes/updates to industry standards.

METHODOLOGY

This project continued the same methodology used by Dudas; namely collating utility specifications and surveying to establish purchasing data and impressions. The authors asked for the last version of Dudas' survey provided to utilities, but was unsuccessful in obtaining it.

Data Collection

Cable specifications, typically issued by utility standards groups, were requested. These documents usually specify permissible cable constructions, proper cable identification, and the required testing for specific applications. A subject matter expert extracted information from each cable specification document and then populated a database. Each utility was also requested to supply the cable length purchased in 2014 to reflect the demand. Six thousand entries with 69 fields for each entry were entered into the database to address topics of interest to the industry, i.e. cable designs, cable replacement practices, and accessory design. The specific areas examined in this study appear in [7]. Papers published by Dudas based on the 1993, 1999, and 2004 surveys were also consulted to establish the 20-year trend.

RESULTS

Seventy utilities participated in the study reported here, of which 44 were IOUs and 26 were electric co-ops. The 44 participating IOUs represent 46 million retail electricity customers or nearly half of the total U.S. customers served by IOUs (based on U.S. Electric Utility Industry Statistics published by the American Public Power Association in 2016 [7]). The 26 responding co-ops represent approximately 1.5 million customers or 10% of the retail electric customers served by electric co-ops. The total reported purchased cable length in 2014is approximately 94 million feet (18,000 miles). The margin of error (MoE) of this study is 12% with a 95% confidence level based on participation.

Voltage Class

The most commonly purchased cables are 15 kV class. Nearly half of the purchased length (close to 9,000 miles) is 15 kV rated. Based on the MoE calculated for this study, the percentage of purchased length for 15 kV rated cables could be 38% to 64% (50% +/- 12%) as shown in Figure 1.

The least purchased cable is 5 kV rated, accounting for 0.2% of the total purchased length (38 miles).

Survey data shows that the share of 25 kV class cables in purchased length remained stable (+/-1%) over the past 15 years. The use of 15 kV class cables dropped approximately 4% compared to that of 10 years ago. On the other hand, the use of 35 kV cables has increased 4%. The magnitude of change is, however, within the margins of error of the results and thus not viewed as significant.

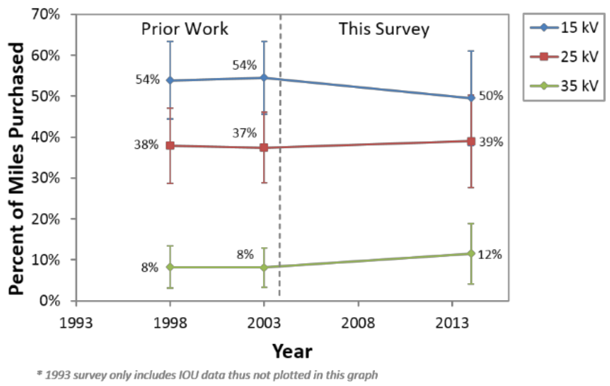

Figure 1 The 15-Year Trend in Purchased Cable Length by Voltage Class including Uncertainty Bands from the MOE Estimate

Conductor

Conductor Material

The majority of surveyed utilities (75% of participating utilities) specify both aluminum and copper conductors for different parts of their systems. A quarter of the participating utilities only specify aluminum conductor, which is more common in cooperatives (14 out of 26 participating cooperatives).

Aluminum composes the majority of IOU conductors and almost all the conductor material used by co-ops due to its lower cost as compared to copper. Copper conductors are more expensive and commonly appear in large conductors (≥500 kcmil) for feeders or #2 AWG conductors for important circuits to justify the cost.

Popular Size

The most frequently purchased cable design has a conductor size of 1/0 AWG, followed by #2 AWG and #1 AWG. The total purchased length of these three relatively small conductors is approximately 60% of the total reported length.

Approximately 20% of the reported cable length has a large conductor size (≥ 500 kcmil), which is most often used in system feeders. The three most commonly purchased conductors are 1,000 kcmil, 750 kcmil and 500 kcmil. The total purchased length for these three conductor sizes constitute about 80% of the purchased length for all large size conductors.

Water Blocking

Moisture is one of the most important factors for water tree initiation and development. The availability of water can be limited by preventing water from traveling down the conductor strands. Approximately 72% of the purchased length (27% solid conductors plus 45% strand-filled conductors) includes water blocking features in its conductor design. This is unsurprising given that solid and strand-filled conductors are the two primary water-blocking conductor designs.

The purchased lengths separated by water blocking feature are not available in past surveys conducted by Dudas. Thus, the trend in utility specification by water blocking feature was generated instead. The percentage of utilities in 2003 specifying non-water-blocked conductor designs increased significantly from 1998. This percentage remained at a similar level in the 2014 survey as compared to 2003 (the change is within the MoE of this study).

Extruded Components

Conductor Shield

The conductor shield is a semi-conductive layer between the conductor and the insulation that provides a smooth interface for electrical stress relief. Manufacturing the semi-conducting material entails dispersing carbon black within a polymer matrix. Conventional conductor shields use furnace black, which is processed by controlled combustion of hydrocarbons. As a result, there is a high level of inorganic contaminants that accelerate water tree development in polyethylene-based cable insulation. In the late 1980's, super smooth/super clean (often called "supersmooth") conductor shield was introduced for MV cables in North America. The supersmooth conductor shield uses acetylene black manufactured from thermal decomposition of acetylene gas. This greatly improves the cleanliness of the compound. Further improvement in the manufacturing process provided a super smooth surface. Figure 2 shows that approximately 1/3rd of the total purchased length has a super smooth conductor shield. A very small fraction (less than 1%) of the purchased length specifies conventional conductor shield. The remainder does not specify conductor shield type, thus implying either conventional or super smooth, but more likely is super smooth given existing data.

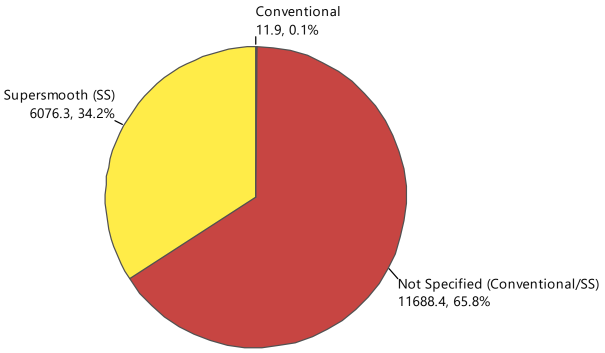

Figure 2 Distribution of Purchased Length in Miles by Conductor Shield Type (Numbers in each category of the graph are the purchased length (in miles), followed by the percentage)

Insulation Material

With premature failures of HMWPE and XLPE insulated cables from water treeing, TRXLPE and EPR have become the preferred alternatives for cable insulation in the US [9 - 11]. The trend in insulation materials reported by Dudas was based on the percentage of utilities specifying different insulation types. Just because insulation materials can be specified on a system does not mean that insulation material was actually purchased/installed. Figure 3 shows the 15-year trend of purchased length by insulation type, which considers the utility's size and captures which cable insulation will be installed. Purchased length data from the 1993 survey is not available to establish a comparable, earlier 15-year trend. A dramatic drop in percent of purchased length occurred for EPR insulated cables from 1998 to 2003 (from 27% to 15%). The demand share has since climbed back to 1998 levels.

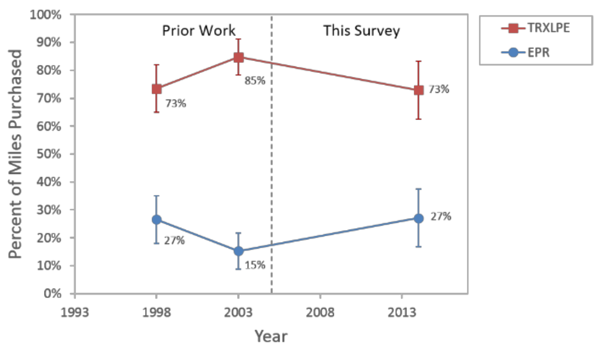

Figure 3:A Fifteen-year Trend in Purchased Cable Length by Insulation Materials.

This work also extended the medium voltage cable installation history [8] (a 35-year view) to a 50-year view using the 2014 reported cable length (this survey) as the average cable installation length per year for the past 10 years. There was no adjustment made to the collated data to reflect missing utilities. Thus, the reported cumulative installed cable length by 2014 is a conservative estimate. The developed estimate is included in **Error! Reference source not found.** and reflects market trends over the past 50 years and captures the installed miles of underground cables by insulation type.

Insulation Thickness

The practice of utilities installing MV underground cables with reduced wall (<100% insulation), 100% insulation, and enhanced wall (>100% insulation) was extracted from prior work and extended with this study to develop a 15-year trend (Figure 4).

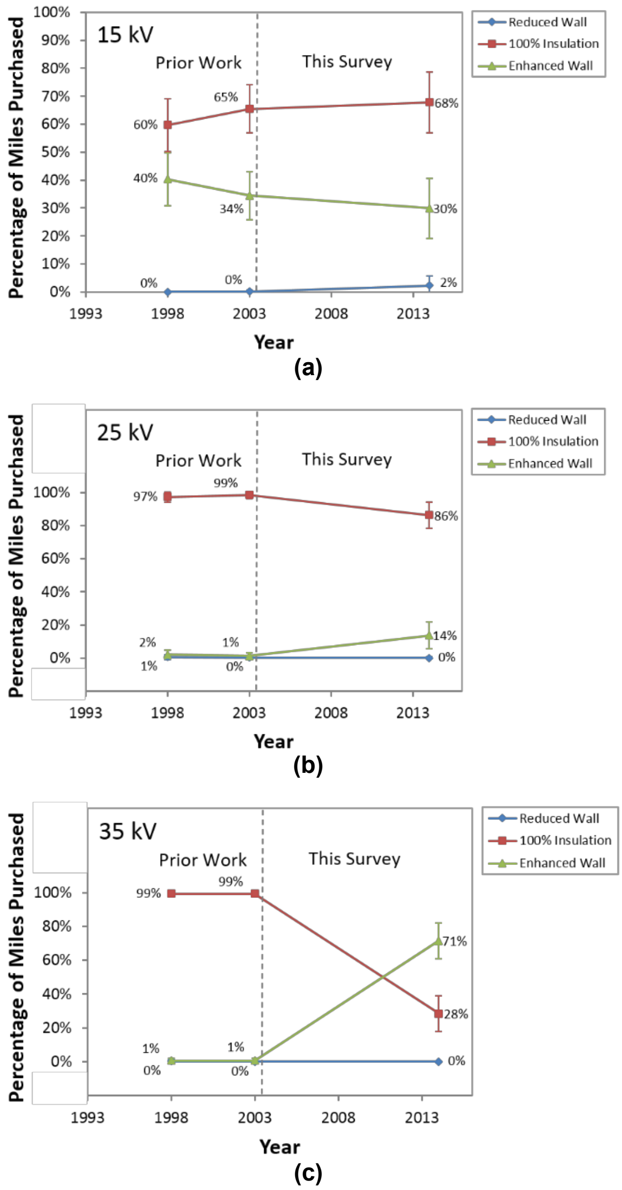

Figure 4: A Fifteen-Year Trend in Purchased Cable Length by Insulation Thickness.

The majority of the purchased length uses 100% insulation for 5 kV, 15 kV, and 25 kV class cables. Extra caution was used for 35 kV class cables as enhanced insulation walls (>100% insulation) seems a preferred choice. Few cables were reported as being purchased with reduced walls. A small percentage (<3%) reduced-wall insulation was purchased for 15 kV class cables and none for 5 kV, 25 kV or 35 kV classes.

It is interesting to see in Figure 4 that:

- Small amounts of reduced wall cables were purchased for MV underground cables (15 kV, 25 kV, and 35 kV) in the past 15 years.
- Cables with 100% insulation are most preferred for 15 kV and 25 kV classes in the last 15 years. The same preference appeared in 35 kV cables in the 5-year range from 1998 to 2003; however, caution prevailed in the industry and the preference has changed to enhanced wall for 35 kV cables in the last 10 years.
- The demand share of cables between 100% insulation and enhanced (thicker) wall varies among the voltage classes.
  a) Considering 15 kV cables, cable with 100% insulation comprises about 60-70% of the purchased length in the past 15 years. A gradual shift in preference from enhanced wall to 100% insulation has been a consistent trend as users gain more experience with 100% insulation cables (Figure 4(a)).
  b) Considering 25 kV cables, there is a 13% increase in the use of enhanced wall during the past 10 years (Figure 4(b)) indicating greater caution by the utilities.
  c) Considering 35 kV cables, the practice has been more conservative. There is a dramatic change (70% increase) in the demand of MV underground cables with enhanced wall (Figure 4(c)) in the last 10 years.

Accessories

Prior work focused on medium voltage underground cables. A number of issues on accessories are worth exploring. Thus, utilities were asked the types of joints, connectors, and terminations they purchased in 2014 and 2015 in a separate survey. Seventy-four utilities participated this part of study. The topics in this section are new to prior work and so have no trend as that to review. It is important to note that the following discussion does not account for the effect of purchase volume.

Joint Technology

Three joint technologies including heat shrink, cold shrink and premold, were reported being purchased by the participating utilities in 2014 and 2015. The majority of the responding utilities purchased cold shrink joints. Over two-thirds of respondents indicated they purchased pre-molded joints in these two reporting years. It is noted that the sum of the percentages for the three joint technologies add to more than 100% implying many utilities use more than one joint technology.

Nearly one-fifth of the responding utilities (21% in 2014 and 18% in 2015) purchased cold shrink joints only and 6% purchased pre-molded joints only. The remainder purchased more than one type of joint. The practice did not change significantly from 2014 to 2015.

Connector Designs

The crimp connector is a traditional design that has been on the market for over 40 years. It requires special crimping tools for installation, and the proper selection of the die is the key to ensuring a reliable connection. A significant portion of the responding utilities indicated that they purchased crimp connectors only, although the percentage decreases from 2014 to 2015 (75% in 2014 and 50% in 2015).

Shear bolt is a modern mechanical design that has been on the market for around 20 years. Approximately a quarter of the responding utilities indicate that they purchased both crimp and shear bolt connectors in 2014 and 2015. None of the responding utilities purchased shear bolt connectors exclusively in 2014. The percentage, however, increased to 3% in 2015.

Over half of the responding utilities (75% in 2014 and 51% in 2015) purchased a single connector design. Greater numbers of utilities appear to have transitioned from a single connector design to a hybrid of both connector designs (from 25% in 2014 to 48% in 2015).

Cable Choice

Utilities were asked to rate the importance of the factors listed in Figure 5 (randomized) based on their relative impact on the purchasing decision-making process. The survey allowed each respondent to rate each factor from not important, somewhat important, moderately important, very important to the single most important factor. A compound score was calculated based on participants' responses.

Figure 5 shows that expected life and experience at their utilities are the most important factors for decision-making, followed by compatibility with accessories, and cable manufacturer reputation. Cable cost is not one of the top five influencing factors. It is interesting to note that experience at a neighboring utility and industry presentations are at the bottom of the ranking list.

Similar questions but fewer factors (i.e. expected life, cost, flexibility, ease of terminating, and temperature rating) were surveyed in prior work by Dudas. The 2004 ranked factors were similar in order to the rankings from this study (2014). The rankings in 2004 also indicate that expected life was the most important cable selection criteria; a priority that remains unchanged. This information is of increasing importance as many existing installed cables (~600,000 miles) are 30+ years old and utilities want more insight into their expected service life. There is not, unfortunately, an existing testing program that can obtain such information. The closest effort in this area is the Accelerated Cable Life Test (ACLT).

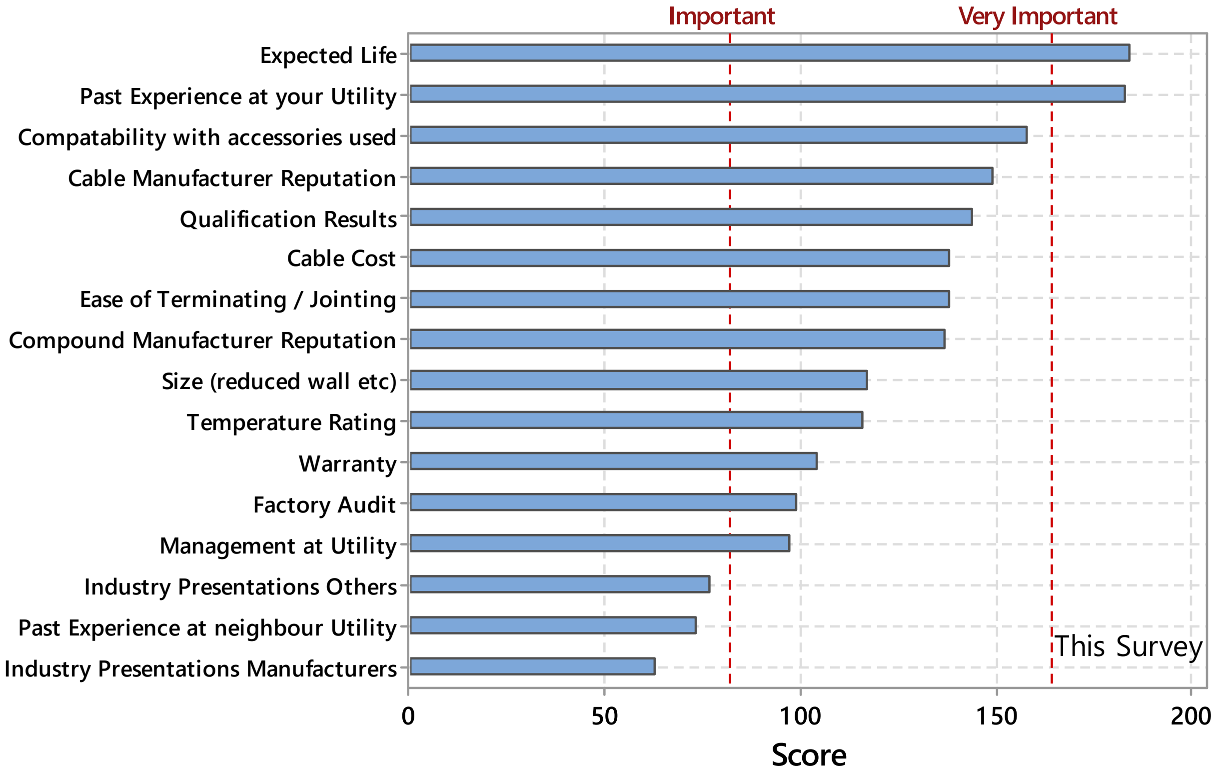

Figure 5: Ranking of Important Factors for Cable Selection (2014)

CONCLUSIONS

The focus of this study is medium voltage underground cable, which makes up on average 21% of the primary distribution system for the surveyed utilities. This provides some context for the detailed results presented in this paper. The major findings may be summarized for cables purchased in 2014-2015 as follows:

- 9 in every 10 miles of medium voltage underground cable purchased have an aluminum conductor;
- 3 in every 10 miles of medium voltage underground cable purchased have a conductor size of 1/0 AWG;
- 7 in every 10 miles of medium voltage underground cable purchased have some type of water blocking feature in their conductor design, namely solid conductor or strand-filled conductor;
- At least 3 in every 10 miles of medium voltage underground cable purchased uses a supersmooth conductor screen;
- 7 in every 10 miles of medium voltage underground cable purchased uses TRXLPE as the cable insulation;
- 5 in every 10 miles of medium voltage underground cable purchased are 15 kV voltage class;
- 7 in every 10 miles of medium voltage underground cable purchased use the 100% insulation level;
- At least 7 in 10 utilities purchase crimp connectors only; however, more utilities are switching from a single connector design to allow both crimp and shear bolt connectors;
- 7 in 10 utilities purchase more than one type joint technology with cold shrink being the choice of most utilities;

The margin of error of this study is 12% with 95% confidence level based on survey participation.

FUTURE WORK

As technology evolves and maintenance practices change, the authors plan to revisit this every 5 years to extend / predict trends.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the NEETRAC Members in publishing these findings.

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GLOSSARY

AEIC: The Association of Edison Illuminating Companies
NRECA: National Rural Electric Cooperative Association
IOU: Investor Owned Utilities
ACLT: Accelerated Cable Life Test