Limiting Load Flow

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1. Introduction

The required ampacity of electrical distribution cabling onboard ship depends on the worst-case flow of power through that cable. For a feeder cable supplying a single load, or a small set of loads, calculating this worst-case flow is usually determined by examining the highest operating load of the equipment powered via the cable. In distribution cables where there can be sources (generator sets) or loads on either end of the cable, the calculations are not so simple. These calculations require a detailed understanding of the loads and how the ship is anticipated to be operated over its service life. In the earliest stages of design, the details required for this level of understanding are not known; loads are often estimated rather than identified, and system concepts of operation are vague at best. In the earliest stages of design, the Electric Power Load Analysis (EPLA) is often estimated through analogy; loads are allocated to distribution system switchboards and load centers based on engineering judgement.

The Limiting Load Flow (LLF) method enables determining an upper bound for the power flow through a cable based on source (generator) full load ratings and aggregated loads for each load center or switchboard. The loads are generally provided by an EPLA for various operating conditions (anchor, shore, cruise, functional, etc.) and ambient conditions (10 °F, 59 °F, and 100 °F). These loads should include margin and service life allowance.

For a given operating condition, the LLF compares the maximum magnitude of the power provided by sources on one end with the maximum magnitude of loads on the other end. The smaller of the two is the LLF in one direction; the smaller of the two limits the power flow through the cable in that direction (for the specific operating condition and ambient condition). The larger of the LLFs in both directions is the LLF for the cable for the specific operating condition and ambient condition. The overall LLF is the largest LLF for any operating condition and ambient condtion.

Certain loads (and sources), such as vital loads, can connect to the power system via either a normal or an alternate connection; a bus transfer is used to connect the load (or source) to one of two different load centers / switchboards. If both the normal and alternate connections are on the same end of the cable, then the load (or source) is only considered on that end. On the other hand, if the normal connection is on one end of the cable, and the alternate connection is on the other end of the cable, then the load (or source) is added to both sides of the cable.

If loops exist in the network such that the ends of a cable are connected via other cables (forming a loop), then the number of unique loops is determined, and combinations of cables up to the number of unique loops are eliminated. If the resulting system doesn't have a loop, then LLF is determined; the maximum LLF across all the combinations is the LLF for the cable.

The results of the LLF analysis is the maximum power flow through the cable; this power can be readily converted to a current assuming the voltage is at the nominal system voltage. The maximum current allowed for a single cable, or a set of parallel cables depends on the ambient temperature of the cable, and how the cable is mounted in relationship to other cables in a cableway.

The program `llf.exe` performs the LLF calculations for a power system defined in an `xml` file. The remainder of this document explains how to use `llf.exe` and create the power system definition `xml` file. The program is written in C and compiled using the Microsoft Visual Studio C compiler via the `nmake` command and associated `MAKEFILE`.

2. Syntax

The llf.exe program is intended to be run from CMD (Command Prompt) within Microsoft Windows.

```
llf.exe xmlfile.xml -d

      xmlfile.xml   input xml file

      -d            debug flag (optional)
```

3. Input `xml` File Format

```
<limloadflow>
<comment> comments </comment>
<include> include.xml </include> contents of include.xml inserted here
      This tag is optional
<output>
      <filename>   file.csv   </filename> prints to screen if not defined
      <condition> Condition Name </condition>  can have many
      The limiting load flow is calculated for all
      of the conditions listed here.
</output>
<debug> 0 </debug>  sets the debug flag if 1
<lc> can also use <load><pgm><pmm><pcm><bus_node><sb>
      <name> load center name </name>
      <condition>  Can have multiple condition tags
            <name> Condition_name </name>
            <generation> val </generation> (val should be in kW)
            <load> val </load> (val should be in kW)
      </condition>
</lc>
<cable>
      <name> name </name>
```

```
      <lc> name </lc>
      <lc> name </lc>  must have two lc tags indicating the ends of the cable
</cable>
<bt>  bus transfer
      <name> name </name>
      <lc> name </lc>
      <lc> name </lc>  must have 2 lc tags (normal and alternate connection)
      <condition>  Can have multiple condition tags
            <name> Condition name </name>
            <generation> val </generation> (val should be in kW)
            <load> val </load> (val should be in kW)
      </condition>
</bt>
```

4. Program Flow

```
Initialize structures
Read in command line
Read in xml file
Parse xml file
Error check resulting network
Identify each independent system
Loop through each cable
      Determine which independent system the cable is in
      Eliminate the cable from the independent system
      Determine the number of independent systems in the modified system
      If the number is exactly two, then this is the only run – no loops
      Otherwise the number should be one, indicating that there are > 0 loops
            Calculate number of loops – number of cables – number of LC + 1
            Create list of runs, each with a candidate cable sets to remove
                  Each set has 1 to Nbr of loops cables in it
            For each cable set, remove the cables
                  and see how many independent systems remain
                  Remove candidate sets where the number is not 2
                  Remove candidate sets where both ends of the cable are in
                  same independent system
      For each run, and for each condition, calculate the limiting load flow
      Determine the maximum limiting load flow for all runs
Print results
```

5. Examples

Eight examples, also used as part of verification testing, are provided. These examples are in folders named Vtest1 through Vtest8. Each folder contains the .xml file containing the network definition; a .jpg file that graphically depicts the network; an .xlsx Microsoft Excel File with the solution worked out independently; a .csv file containing the results of the analysis; and a .txt file with an excerpt of the .csv file that is used as part of the verification process. A batch file, vtest.bat, is used to perform the verification testing.