A Systematic Approach to Light Load Calculation for DG Un-Intentional Islanding

Le Chen, *Member, IEEE,* Joseph Saylor, *Member, IEEE,* Aaron Clark, *Member, IEEE,* Jiecheng Zhao, *Member, IEEE,* Francisco Velez, *Senior Member, IEEE*, Hesen Liu, *Member, IEEE,* Yilu Liu, *Fellow, IEEE*

***Abstract* —With the influx of distributed generation (DG) penetration, power utilities have adopted active anti-islanding protection methods to prevent an unintentional islanding condition. One commonly used protection scheme is implemented through the use of a transfer trip from the upline connected substation to the DG facility and is required when the capacity of connected DGs exceed a certain threshold of local minimum load. The threshold established by standard IEEE 1547.2-2009 states that a 3:1 minimum load to generation ratio is acceptable to ensure the DG will not sustain an unintentional island. However, the term "minimum load" is not precisely defined in any standard, and in practice, a light load value is chosen by engineers through manual methods that can be inconsistent, not representative and change drastically based on various cases. To solve this problem, this paper proposes a new light load calculation method creating consistency and better accuracy; the method has been implemented in .NET C# application and is used within Dominion Energy.**

***Index Terms* — DG, protection, anti-islanding, un-intentional islanding, IEEE 1547, light load, EMS.**

I. INTRODUCTION

Distributed generation (DG) installed in parallel with distribution circuits can operate reliably while interconnected with an utility system. However, if the upstream utility system becomes disconnected from the DG due to any abnormality, it is possible for the DG site to remain energized thus forming an islanded system. This un-intentional islanding situation results in various risks, including personnel safety and equipment damage [1].

Whether a DG can sustain an island depends on the ratio of load to DG capacity: an island cannot be formed if the load capacity is much larger than generation. For a given capacity of DG, un-intentional islanding tends to occur when loads become smaller. Therefore, In IEEE 1547[2, 3], a 3:1 expected minimum load to generation ratio is recommended for the nearest upline device from the point of interconnection (POI) to ensure the DG site will not sustain an unintentional island.

To validate the calculation is within the margins of worst case acceptability, maximum DG output and minimum load are used for calculations. The DG nameplate capacity is used for maximum output, and light load capacity of the interconnected circuit is used instead of minimum load values in practice.

Contrary to the term "minimum load", the light load value is not obtained by simply sorting the load values and selecting the smallest. There are a lot of zeros and irrelevant non-zero values which do not represent the actual light load. Therefore, an effective and systematic method is needed to find a reasonable light load and this, the purpose of this paper.

When calculating the light load, typically one would use historical load data provided by an Energy Management System (EMS). This data can cover a couple of months to several years, all of which can contain zero values. Zero values appear because the minimum load value is vulnerable to abnormal conditions, such as disturbance events, communication dropouts, and even equipment failure. For example: if a fault occurs on a feeder circuit, the feeder relay detects the fault and trips the feeder breaker; hence, the measured load data output will be zero. By averaging the load data into half hour increments instead of observing all of the raw data provided, some abnormal conditions can be filtered out, but not all. Fig. 1 illustrates the first 200 load values of a 34.5 kV distribution feeder (feeder A) sorted from smallest to largest within a one year time span (each value is the average of a half hour time span of raw data).

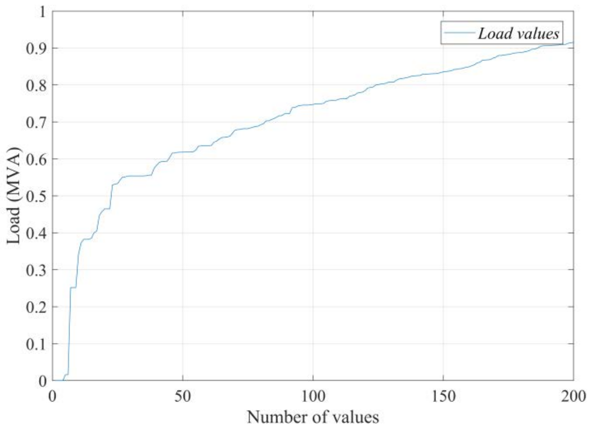

Fig. 1: Load data of a 34.5kV distribution feeder A in increasing order

Le Chen is with the University of Tennessee, Knoxville, TN, USA 37996. (E-mail: lchen52@utk.edu).

Joseph Saylor, Aaron Clark, Jiecheng Zhao, Francisco Velez and Hesen Liu are with Dominion Energy, Richmond, VA 23220 USA. (E-mail: joseph.r.saylor@dominionenergy.com, aaron.y.clark@dominionenergy.com, francisco.velez@dominionenergy.com, jiecheng.zhao@dominionenergy.com, hesen.liu@dominionenergy.com).

Yilu Liu is with the University of Tennessee, Knoxville, TN, 37996, USA and also with Oak Ridge National Laboratory, Oak Ridge, TN, 37830, USA. (E-mail: liu@utk.edu).

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As shown in Fig. 1, the first several data points are zeros and cannot be used for any light load calculations. However, if we use any positive value ranging from 0.01 to 0.92 MW, our light load to generation ratio calculation will result in significant fluctuations due to the large variation in loading values.

Due to the lack of guidance to determine what qualifies as the definition of minimum loading, it has been difficult to quantify what is the correct light load value. Currently, the most descriptive statement about the definition of minimum load can be found in IEEE 1547.7-2013 "*Load data for each line section may be readily available or reliably estimated from data available*." [4]. As far as the authors are concerned, the practice in some power utilities is manually choosing a non-zero light load value by an engineer (e.g. manually choosing light load from values illustrated in Fig. 1 or some other visual diagram).

Light load to generation ratio is important for deciding whether a transfer trip (TT) scheme is required to disconnect a DG facility from the source (utility). For the Dominion Energy system, TT is installed from each upline utility sectionalizing device to be able to transmit a trip signal to the DG site recloser located at the POI in the event of any abnormality from the source. Due to the addition of a communications channel needed for signal transmission, installation of TT is not a small investment. Therefore, incorrect data within light load calculations (e.g. calculating a light load lower than actual light load) can result in unnecessary additional investment, while other kinds of errors (e.g. calculating a light load higher than the actual light load) can result in a potential un-intentional islanding, thus causing unnecessary risks.

The IEEE "Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection" [4] states the accuracy of calculations needed is dependent on the amount of aggregated DG capacity as a percentage of the minimum load. With the rapid increase of DGs the accuracy of load needs to be improved.

To solve this problem, this paper proposes a new light load calculation method that is consistent and has better accuracy. In Section II, the calculation process of the proposed method is described. Implementation and case studies are presented in Section III. Conclusions are drawn in Section IV.

II. CALCULATION METHODOLOGY

A. Principle of Light Load Calculation

The principle of light load calculations is to find a real minimum value that is immune to abnormal impacts and actually reflects the true profile of a light load.

To this end, two parts are used for light load calculations: the first part is to filter out invalid values; and the second part is to find the statistically significant values that best reflect the true light load.

B. Screening Out Invalid Data

All the data used in this study was taken from historical EMS data from the Dominion Energy Data Management System. The initial step in our process is to screen out invalid data, which includes zero data and duplicate data. An example of finding zero invalid data on 34.5 kV distribution feeder B are shown in Table I below:

Table I: Load value of 34.5 kV distribution feeder B

Date	Time	Load Value(MW)
10/12/2018	8:00 AM	0
10/12/2018	8:30 AM	0
10/12/2018	9:00 AM	0
10/12/2018	9:30 AM	0.259040936
10/12/2018	10:00 AM	7.481720734
10/12/2018	10:30 AM	22.70467793
10/12/2018	11:00 AM	27.93082524
10/12/2018	11:30 AM	28.69948639
10/12/2018	12:00 PM	28.37587616

Abnormal events depicted in Table 1 are representative of the load values from 8:00 AM to 9:00 AM being zero, and the close approximation to zero at 9:30 AM. To eliminate the impact of a zero value and its adjacent small load value within light load calculations, whenever a zero load value is found, all load values that day will be eliminated from the calculation.

Another form of invalid data was found to be the introduction of duplicate load data values (sometimes these values can remain unchanged for several days). Small load values usually appear during the transition from duplicate data to normal data. Due to this feature of duplicate invalid data, whenever duplicate data was found, the duplicate amount of data is counted and compared to a duplicate number setting threshold. This threshold accounts for unchanged load conditions during late night hours, usually 12:30 AM to 04:30 AM. During this time load values may remain unchanged. The threshold setting will avoid mistakenly screening out valid data. If this threshold is exceeded, the data for that day is discarded.

C. Time Filtering

It is specified in [4] that the load to generation ratio should be calculated within the time that the DG is expected to be in operation. For wind based DG, light load values are considered for twenty-four-hour periods, and no additional time filtering is needed. For solar DG, time filtering should be limited to daytime hours only (from sunrise to sunset) and adjusted according to the season. For accurate modeling of light loading values, the time used for solar DG is as follows: from May to Aug. the time range is 6:00 AM to 6:00 PM, and the remaining months' time range is 8:00 AM to 5:00 PM.

D. Outlier Data Process

After data processing and time filtering, most invalid data have been filtered out; however, some outliers may still exist and impact the light load calculations. Table II illustrates a typical situation:

Table II: Load values of 34.5 kV distribution feeder C

Date	Time	Load Value(MW)
10/24/2018	11:30 AM	20.31799543
10/24/2018	12:00 PM	20.05072786
10/24/2018	12:30 PM	19.92281286
10/24/2018	1:00 PM	18.05769755
10/24/2018	1:30 PM	5.86203355
10/24/2018	2:00 PM	13.13575354
10/24/2018	2:30 PM	13.56086514
10/24/2018	3:00 PM	13.68796275
10/24/2018	3:30 PM	13.57066654

Due to abnormal situations, erroneous outliers in load data can be observed, such as at 1:30 PM in Table II. Since the load data is calculated using the average of a half-hour period, the dip could stem from a temporary interruption of the source feeding the load. One possibility is the feeder breaker opened after a transient fault and successfully reclosed later, which would cause a gap in the loading data being measured. This kind of situation is inevitable, and may happen several times within a yearly time scale.

To avoid the negative impact on light load calculations, an outlier data processing method is proposed:

1) First, sort all the remaining data points after invalid data processing and time filtering and assume the total number of data is N.
2) Now take the initially sorted data and calculate the ratio of each point with the previous data point in ascending order within the first half of the data (sorted by load value from smallest to largest), as shown in (1):

$$r_i = \frac{Load_i}{Load_{i-1}}, i \in \left[2, floor(\frac{N}{2})\right] \tag{1}$$

3) After Step 2, a sequence of ratios between the sorted load values is acquired. The ratio sequence is then compared to a given setting threshold, and the last index of all the following ratios is less than the given threshold, as shown in (2):

$$k = \min\left(\forall\, r_j < r_{SET}\right), j \in [i, floor(\frac{N}{2})] \tag{2}$$

4) $Load_k$ is then the light load.

After sorting by value, the ratio of this data point and previous adjacent data point reflects the rate of change for the load values. Under any normal situation, the change in load is asymptotical, either gradually increasing or gradually decreasing. Meanwhile, load data during abnormal situations are random in value. By comparing the previous load value to their adjacent point after sorting, outliers caused by an abnormal load condition can be discarded if there is a big enough discrepancy between data sets.

To further elaborate the process, an example is shown in Fig. 2. It illustrates the first 30 values after the process described in II.B and II.C of 34.5 kV distribution feeder C. The values of the first ten data points and the last value are labelled.

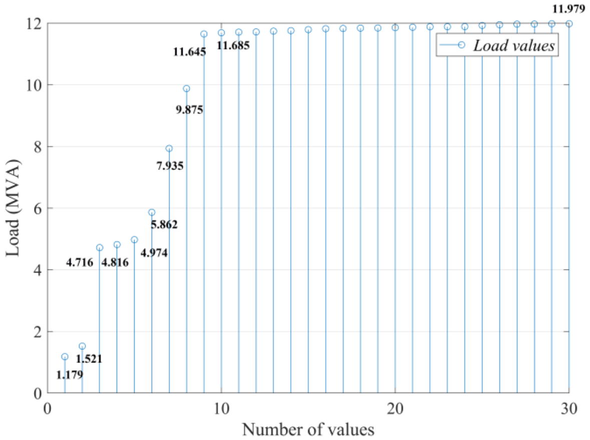


Fig. 2: Load data of feeder C after previous process

Ratios of the first ten values can be calculated using the label shown in Fig. 2. These values are r_2:1.29, r_3:3.10, r_4:1.02, r_5:1.03, r_6:1.18, r_7:1.35, r_8:1.24, r_9:1.18, r_{10}:1.00, and in this case $r_{SET} = 1.1$. Because $r_2 > r_{SET}$, the first point is discarded, and the second point is also discarded due to $r_3 > r_{SET}$, r_4 is less than 1.1, and the third value is kept for now and is the minimum value. When r_5 comes in, the min is still the third value. However, r_6 exceeds the setting threshold, while the sixth value is now kept as the min, and previous 3~5 values are discarded. Likewise, if we keep going through this iterative approach, all r_i including the ninth value are kept as the final minimum load value.

As shown in the previous process, all outliers can be detected and deleted. In fact, the sixth data value in Fig. 2 is the abnormal situation shown in Table II. For the load values, starting from the ninth value, they all have values close to each other. Therefore, their values are statistically significant and the minimum among them is chosen as the result for the calculated light load.

It should be noted that outliers caused by abnormal load conditions could be equal to or larger than the calculated light load due to the statistically significant characteristic. This type of outlier has little to no impact on light load calculations. If we assume that the ninth value in Fig. 2 is an outlier while the tenth is the true light load, the calculation error for this case is 0.34%, which is much smaller than the manual method and acceptable for the load to generation ratio calculation.

E. *Reference for Validation*

The previous process can calculate light loads that are immune to invalid data caused by short term abnormal situations, but are still vulnerable to relatively long term abnormal situations, such as construction or maintenance. Long term abnormalities result in two conditions that stem from a change in circuit architecture. One being an alternate feed replacing an existing circuit and the second caused by the removal of a circuit entirely, which can cause extreme discrepancy in data and will typically show all data for a given time as zero. Both situations have been proven to result in inaccuracy of light load calculations.

To avoid these long term abnormal situations, a cross-validation method is implemented for calculations of different years. This is on the basis that load change is relatively small. Hence, in this paper, light load of the most current three years are calculated for cross-validation.

F. *Process of Calculation*

The process of calculation is shown in Fig. 3:

In order to successfully follow the calculation method used in Fig. 3, three criteria must be met:

1) Locate the respective name of a circuit or transformer stored in a database (used for data retrieval).
2) Threshold of 10 values (each value comprised of half-hour averages) is utilized in this paper, which corresponds to a five-hour time span.
3) Calculate the comparison ratio between adjacent load values; a larger setting ratio will result in smaller calculations of light loads providing better margin but

worse accuracy. After balancing between the margin and accuracy after several test cases, the ratio is set as 1.1 in this paper.

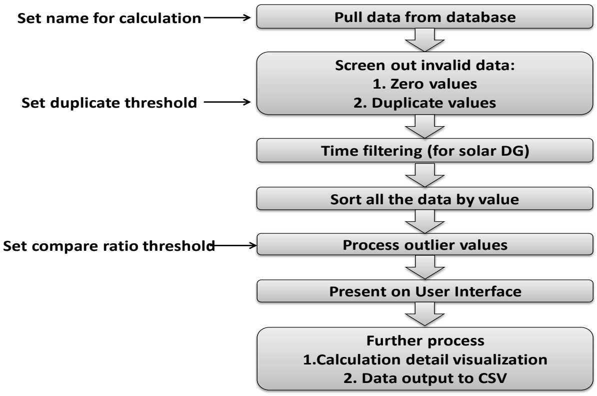


Fig. 3: Flow chart of light load calculation

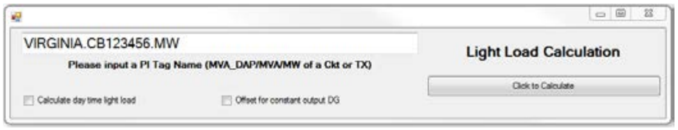
III. IMPLEMENTATION DESIGN

A. *Implementation Platform*

The historical data is stored in OSIsoft PI System allowing for maximum scalability and flexibility; PI SDK is used to retrieve load data from PI database. The data process is implemented in C# and the user interface is implemented using .Net Framework WinForms Application.

B. *Input Interface*

The input interface is illustrated in Fig. 4.



VIRGINIA.CB123456.MW

Please input a PI Tag Name (MVA_DAP/MVA/MW of a Ckt or TX)

☐ Calculate day time light load

☐ Offset for constant output DG

Fig. 4: Input interface of light load calculation application

A PI Tag is the name of data storage, which consists of three parts: substation name, equipment number and data types. The example in Fig. 4 shows the substation name, breaker number of the distribution circuit, and the type of load data.

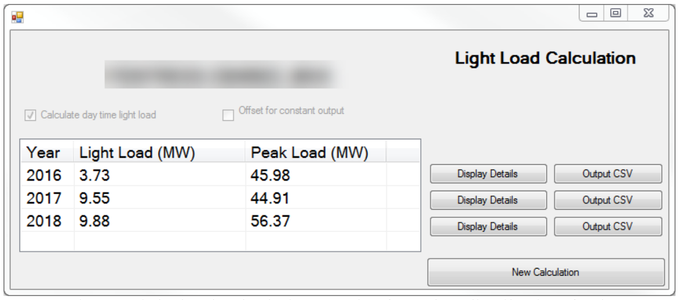
The checkbox "Calculate day time light load" is for solar related DG projects which, when selected, applies time filtering described in Section II.C. The other checkbox is for compensating the load that is masked by DG already in operation on this circuit, if selected, an input textbox will be displayed for inputting DG capacity (when applicable).

It should be pointed out that this check box only applies to DG of constant output, such as biomass. For other DG that is already in operation, true MVA values should be used for calculating light load, which is calculated by the sum of the actual load measured and excluding any down line generation output.

C. *Result Display Interface*

The Fig. 5 illustrates the calculation result of 34.5kV distribution feeder C within a three year time span. The DG in this case is a solar farm, so only day time light load is calculated.

Light load results of the most current three years are presented in the second column of the table. Peak loads are listed in the third column and are references for validating whether the light load is within a reasonable range (peak load is simply the maximum value of load since it is not affected by any abnormal situations).



[redacted]

☑ Calculate day time light load

☐ Offset for constant output

Year	Light Load (MW)	Peak Load (MW)
2016	3.73	45.98
2017	9.55	44.91
2018	9.88	56.37

Fig. 5: Light load calculation result of 34.5kV distribution feeder C

For any result of a given year, there are two options that can be selected: one for displaying details of that year and the other for outputting CSV files. Each of these two functions will be explained along with a case analysis in the following section.

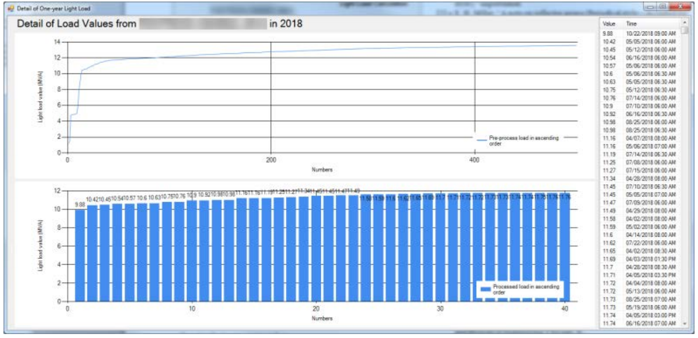
IV. CASE ANALYSIS

A. *Result Overview*

As shown in Fig. 5, the calculated light load for 2017 and 2018 are very close, and both results are within reasonable ranges when compared to peak load values. For convenience, the average of both years can be used as the final result for light load, or further research can be performed via the details of each year's calculation.

B. *Validation Using Detail View*

The detailed view of feeder C of 2018 is shown in Fig. 6.



Detail of One-year Light Load

Detail of Load Values from [redacted] in 2018

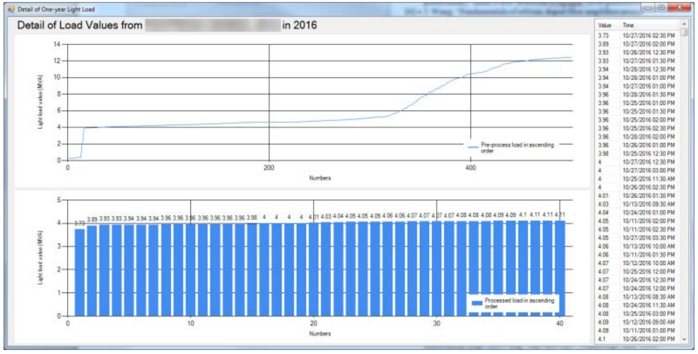
Value	Time
9.88	10/22/2018 09:00 AM
10.42	05/05/2018 06:00 AM
10.45	05/12/2018 06:00 AM
10.54	06/16/2018 06:00 AM
10.57	05/06/2018 06:00 AM
10.6	05/06/2018 06:30 AM
10.63	05/05/2018 06:30 AM
10.75	05/12/2018 06:30 AM
10.76	07/14/2018 06:00 AM
10.9	07/10/2018 06:00 AM
10.92	06/16/2018 06:30 AM
10.98	08/25/2018 06:00 AM
10.98	08/25/2018 06:30 AM
11.16	04/07/2018 08:00 AM
11.16	05/06/2018 07:00 AM
11.19	07/14/2018 06:30 AM
11.25	07/08/2018 06:00 AM
11.27	07/15/2018 06:00 AM
11.34	04/28/2018 08:00 AM
11.45	07/10/2018 06:30 AM
11.45	05/05/2018 07:00 AM
11.47	07/09/2018 06:00 AM
11.49	04/29/2018 08:00 AM
11.58	04/02/2018 08:00 AM
11.59	05/02/2018 06:00 AM
11.6	04/14/2018 08:00 AM
11.62	07/22/2018 06:00 AM
11.65	04/02/2018 08:30 AM
11.69	04/03/2018 01:30 PM
11.7	04/28/2018 08:30 AM
11.71	04/05/2018 03:30 PM
11.72	04/04/2018 08:00 AM
11.72	05/13/2018 06:00 AM
11.73	08/25/2018 07:00 AM
11.73	05/19/2018 06:00 AM
11.74	04/05/2018 03:00 PM
11.74	06/16/2018 07:00 AM

Fig. 6 Detail view of calculation result in 2018

The detailed view (Fig 6) is another method that can be used for validating results or observing any differences amongst data. There are three parts to the detailed view: the first being a line plot of one years' worth of load data pulled from the database, which is shown in the upper left of Fig. 6. For consistent display visualization, data are simply processed by deleting any zero values, filtering specific time intervals (needed for solar DG cases), and sorting by values. The first 500 values are plotted so the general trend of load values increasing can be reflected. The second part is shown on the lower left of Fig 6. In this part the first forty load values after all calculations are processed is presented using a bar plot. The first value among them is chosen as the calculated light load, and the values that follow are adjacent greater load values. This visualization of data will help validate whether or not all the values look successive. The final part comprises of a list of values within the data that are all sorted corresponding to their respective time after all previous processes are accounted for. By this point, validation of the first values collected can be observed within the outputted bar plot.

When comparing the first part within the upper left and the second part on the bottom left, few small load values have been screened out by the calculation process. When taking into consideration the third part on the right (the data values), the first few values are from different months.

The result from 2017 is very similar to 2018 (the detail view is not presented due to the length of this paper). Meanwhile, the light load result of 2016 is quite different when comparing all three years, which goes to show the benefit of using the detailed view for further analysis as shown in Fig. 7.



Detail of Load Values from [redacted] in 2016

Value	Time
3.73	10/27/2016 02:30 PM
3.89	10/27/2016 02:00 PM
3.93	10/26/2016 12:30 PM
3.93	10/27/2016 01:30 PM
3.94	10/28/2016 12:30 PM
3.94	10/28/2016 01:00 PM
3.94	10/27/2016 01:00 PM
3.96	10/28/2016 01:30 PM
3.96	10/25/2016 01:00 PM
3.96	10/25/2016 01:30 PM
3.96	10/25/2016 02:00 PM
3.96	10/25/2016 02:30 PM
3.96	10/28/2016 02:00 PM
3.96	10/26/2016 01:00 PM
3.98	10/25/2016 12:30 PM
4	10/27/2016 12:30 PM
4	10/27/2016 03:00 PM
4	10/25/2016 11:30 AM
4	10/26/2016 02:30 PM
4.01	10/26/2016 01:30 PM
4.03	10/13/2016 09:30 AM
4.04	10/24/2016 01:00 PM
4.05	10/11/2016 02:00 PM
4.05	10/11/2016 02:30 PM
4.05	10/27/2016 03:30 PM
4.06	10/13/2016 10:00 AM
4.06	10/11/2016 01:30 PM
4.07	10/12/2016 10:00 AM
4.07	10/25/2016 12:00 PM
4.07	10/24/2016 12:30 PM
4.07	10/24/2016 12:00 PM
4.08	10/13/2016 08:30 AM
4.08	10/24/2016 11:30 AM
4.08	10/25/2016 03:00 PM
4.09	10/12/2016 09:00 AM
4.09	10/11/2016 01:00 PM
4.1	10/26/2016 02:00 PM

Fig. 7 Detail view of calculation result in 2016

By looking at the first part, one can determine hundreds of load values within the range of 4 MW to 6 MW. Many of the load values illustrated in the second part are also within this range. However, when looking at the right part of Fig. 7, the time of all listed data is between the 11th and 27th of October. Based on this information it appears that a relatively long term abnormal situation occurred at that time, causing low magnitude load values.

From the detailed view, it can be inferred that something wrong or abnormal occurred, and the calculated values for this year are not reliable. For further investigation, data can be output to a CSV file and then analyzed utilizing other tools.

C. *Analysis on Output Data*

As shown in Fig 8, output data pulled from the database starting from October 1st to November 30th can be chronologically sorted and plotted, as shown in Fig. 8.

As seen on Fig. 8, loads between October 9th to October 29th are significantly lower than during other times. Since the abnormal situation lasted 20 days, and a significant number of low magnitude loads were measured, the data cannot be screened out by the outliers filtering method described in Section II. D.

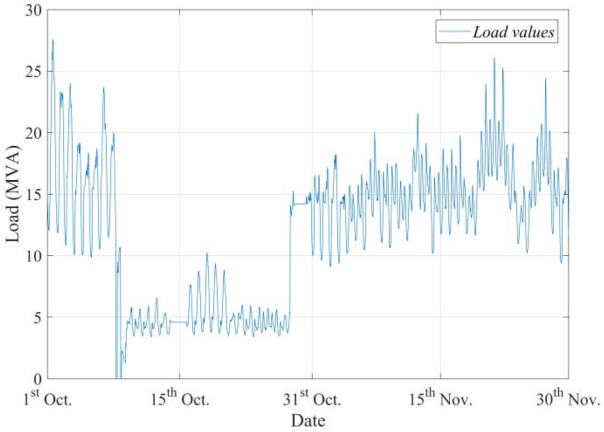


Fig. 8: Data of distribution feeder C from Oct. to Nov. in 2016

It should be pointed out that if the load measured during other times is in a normal condition, the minimum value outside this period should be the considered as the light load. And the minimum value in this case is 9.49 MW on 05/15/2016. This value is very close to the result from 2017 and 2018. This further validates that the calculations for 2017 and 2018 are reliable.

V. CONCLUSION

Accurate light load values for devices (such as a distribution circuit breaker) can be challenging to obtain in practice due to erroneous data. By utilizing the calculation method and corresponding program proposed by this paper, engineers can streamline the process and ensure consistency while reducing the time and cost it takes to complete light load studies. As DG continues to grow and connect to the grid, the need for methods to automate, standardize and streamline processes is essential to ensuring the safety and reliability of the grid.

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