Detection and Minimization of Unbalanced Load by Using Smart Meter Data

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Abstract

Nowadays, the smart meter system has been implemented and installed much more than before, which means more consumption datasets have been measured and collected in the PEA data system. Thus, this study has set the main objective to be utilizing smart meter data for the unbalance current reduction. Because distribution transformers, which are operating in unbalance, can lead to the failures and technical loss increasing. There are two phase-swapping algorithms proposed by this study whose objectives are the same but different in strategies. By integrating smart meter data with topology network data, both proposed algorithms can help to reduce the unbalanced current percentage and reduce manual working processes for PEA.

KEYWORDS: Smart Meter, Data Analysis, Unbalanced Current Reduction, Technical Loss Reduction

1. Introduction

Advanced Metering Infrastructure (AMI) system has been newly implemented for PEA to upgrade our grid to be smart grid. AMI meters measure and collect the consumption data of residential consumers every 15 minutes, which is more frequent than the manual reading method. Thus, there will be so much data stored in the PEA database system. By just storing these datasets inside our system may not be that useful. Therefore, applying data analysis on these datasets is the one effective way to make them more useful. Moreover, by integrating datasets from various related sources, the performances and outcomes of data analysis processes can be more consequential. So, this study has been trying to utilize consumption data from AMI integrated with topology network data from Geographic Information System (GIS) to reduce technical losses in the distribution system by proposing phase-swapping algorithms to reduce unbalanced current percentage.

2. Literature Review

G. Bao & S. Ke (2019) [1] designed a residential load transfer device for a low voltage distribution network that can deal with a three-phase imbalance problem by changing loads' connecting phase. The practical experimental results showed that the proposed method could help reduce the three-phase unbalance rate by changing the connection phase of the load. Also, the optimal swapping strategy has been proposed using the improved multi-population genetic algorithm with a multi-objective policy. Moreover, they have reviewed several pieces of research about phase-swapping strategy algorithms, as shown in Table 1.

G. Grigoras et al. (2020) [7] proposed a new phase load balancing algorithm that can be implemented in low voltage distribution networks with hybrid structures of the consumption points (switchable and non-switchable consumers). This algorithm can work in real-time mode and offline mode. It was tested in a real network, and the results also were compared with other algorithms such as heuristic algorithm and particle swarm optimization. Their compared performances revealed that the proposed algorithm was better than others in terms of unbalance coefficient. Moreover, they also discussed the state-of-the-art of phase load balancing implementation, as shown in Figure 1.

Table 1. Phase-Swapping Strategy [1].

Ref-Year	Method
[2]-2007	A heuristic method with minimizing power loss as an objective function
[3]-2007	Fuzzy Logic with minimizing power loss as an objective function
[4]-2011	Ant colony algorithm with minimizing unbalanced current as an objective function
[5]-2014	Genetic algorithm with voltage imbalance and penalty factor as an objective function
[6]-2016	Particle swarm with minimizing power loss as an objective function

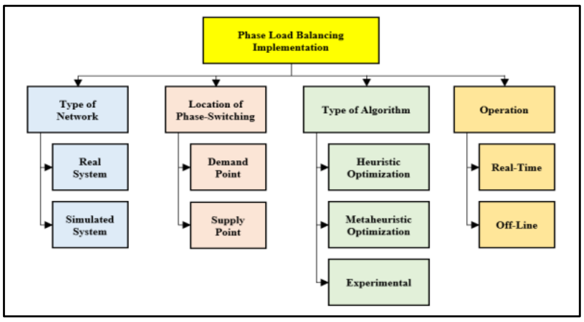

Figure 1. Phase Load Balancing Implementation [7].

3. Methodology

The overall process can be shown in Figure 2. There are two main data sources which are 1) consumption data from AMI (Pattaya City, Thailand) and 2) network topology information from GIS. All gathered data should be in the year 2020. The threshold of the current unbalance percentage is equal to 20%, which is defined by PEA's standard [12]. This study proposes 2 phase-swapping algorithms, which are 1) Average Hourly Resampling (AHR) and 2) Maximum Current Datetime (MCD) algorithms.

3.1 Data Gathering and Preparing

Datasets from the two aforementioned sources will be provided by PEA. Then, they should be prepared before feeding them to the next step. To prepare data, it contains the following processes. First, all gathered data will be cleaned and missing values will also be taken care of. Then, both cleaned datasets will be labeled according to distribution transformers where each meter belongs to. After that, the electricity consumption data for each transformer will be ready to be analyzed. This study has selected 3 transformers, as shown in Table 2.

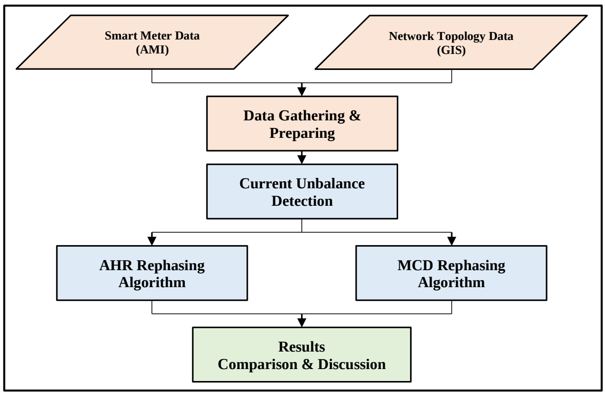

Figure 2. Overall Methodology for This Study.

Table 2. Selected Distribution Transformer.

Rated (kVA)	Characteristic
250	Local Business Area (LBA)
160	Local Living Area (LLA)
160	Wealthy Living Area (WLA)

3.2 Unbalanced Current Detection

Those prepared datasets, from section 3.1, will be calculated for the current unbalance percentage by data-points (datetime) using Equation 1. Then, calculated values will be processed to find the statistical values representing the current unbalance status for each transformer. For this study, if the median value of unbalance percentages is greater than or equal to 20%, that transformer will be labeled as an unbalanced distribution transformer.

$$\%Un = \frac{I_{max} - I_{min}}{I_{max}} \times 100 \qquad (1)$$

Where:

$\%Un$ is percent of current unbalance

I_{max} is maximum phase current (A)

I_{min} is minimum phase current (A)

3.3 AHR Phase-Swapping Algorithm

The first proposed algorithm is called AHR. This method is trying to help reducing current unbalances by rephasing meters based on the average hourly resampling datasets. To briefly explain, consumption datasets will be resampled according to hours in a day by applying average strategy. Thus, there will be 24 consumption datasets for each transformer and feeder as the references for the unbalanced current percentage calculation. Then, meters will be rephased respectively from the maximum phase current to the minimum phase current. Each meter can only be rephased one time. The rephasing process will be stopped if the new calculated unbalance percentage is lower than 20% or the meter that has been rephased previously, is needed to be rephased again. Finally, there will be 24 rephasing results provided by this algorithm. Only the best rephasing order, with the lowest new calculated, unbalance percentage, will be selected for each transformer and feeder. The flow chart of this algorithm can be shown in Figure 3.

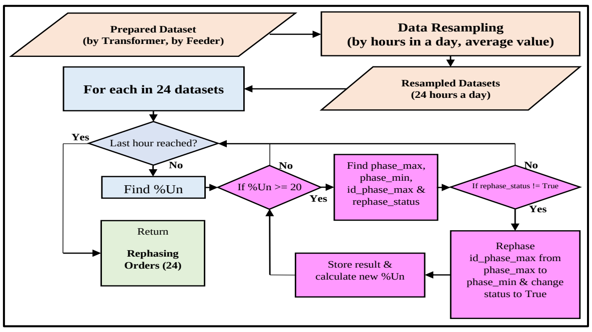

Figure 3. AHR Algorithm Flow Chart.

3.4 MCD Phase-Swapping Algorithm

The second proposed algorithm is called MCD. This method is trying to help reducing current unbalances by rephasing meters based on the specified maximum current datetime. To briefly explain, consumption datasets now will be searched entirely for only one specific datetime with the most current value. Thus, there will be only one reference point for each transformer and feeder's current unbalance percentage calculation. Then, meters will be rephased in the same fashion mentioned in section 3.3. Finally, rephasing results and rephasing order will be provided by this algorithm for each transformer and each feeder. The flow chart of this algorithm can be shown in Figure 4.

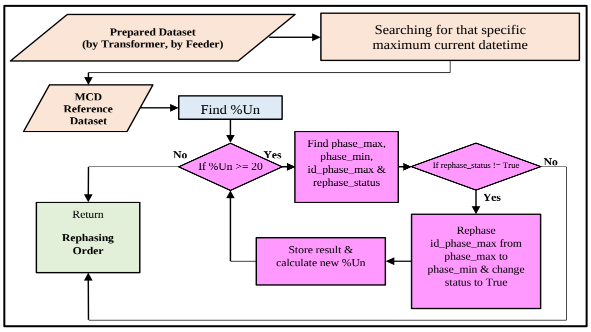

Figure 4. MCD Algorithm Flow Chart.

3.5 Phase-Swapping Results Comparison

After both processes have been finished, their rephasing results for each transformer and each feeder will be compared. There are 3 statistical values of current unbalance percentages to be analyzed which are 1) average or mean 2) median and 3) standard deviation. These values after rephasing should be lower than before rephasing. The algorithm with the lowest median value of the current unbalance percentage will be selected.

4. Result & Discussion

The methodology above will be created and processed using computer programming by Python language. It is one of the most popular programming languages nowadays. Many open-source software and libraries are available online, along with their friends and string sharing communities [8]. Thus, this study will also use some of those open-source modules, which are Pandas [9], Numpy [10] and Matplotlib [11].

4.1 Number of Meters

Figure 5. displays the number of meters by phase for each transformer and feeder before rephasing. There are 2 main types for residential customers, which are 1) single-phase and 2) three-phase meters. However, only single-phase meters can be rephased and included in Figure 5.

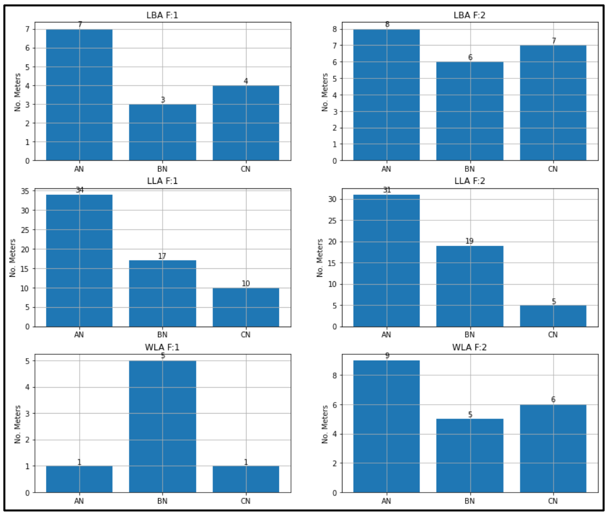

Figure 5. Number of Meters by Phase.

4.2 Unbalanced Current Detection Results

By processing the method from section 3.2, the current unbalance percentage values for each transformer and feeder can be shown in Figure 6. It can be seen that most of the time in 2020, every transformer has been operated over the current unbalance percentage standard (20%).

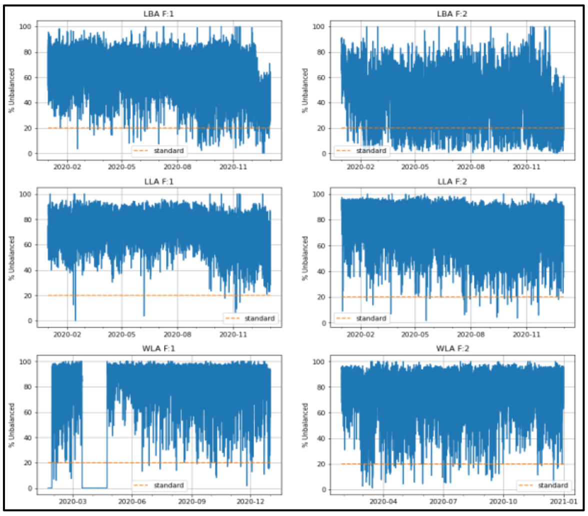

Figure 6. Unbalanced Current Percentage in 2020.

Figure 7 illustrates the daily average current supply for each transformer and feeder. It can be seen that unbalance percentages were fluctuated all day (24-hour). Also, the statistical values of the current unbalance percentage in 2020 (before rephasing) can be shown in Table 3.

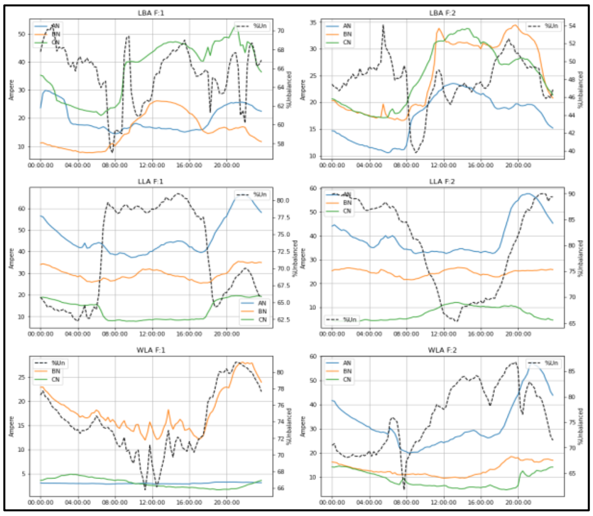

Figure 7. Daily Average Current (before rephasing).

Table 3. Unbalance Percentage (before rephasing).

Tr	Feeder	Average (%)	Median (%)	Standard Deviation
LBA	F1	65.50	68.36	14.50
	F2	47.82	48.69	17.77
LLA	F1	71.93	72.20	11.79
	F2	80.23	84.53	13.57
WLA	F1	73.94	85.59	30.21
	F2	76.14	78.71	14.94

4.3 AHR Phase-Swapping Results

After rephasing meters using the AHR algorithm from section 3.3, the daily average current supply results can be shown in Figure 8. It can be seen that unbalance percentages are less fluctuated than in Figure 7. Moreover, mean and median values are also lower than values from Table 3, which the results in Table 4 can confirm.

Table 4. Unbalance Percentage (AHR rephasing).

Tr	Feeder	Average (%)	Median (%)	Standard Deviation
LBA	F1	62.03	64.90	20.57
	F2	46.45	47.38	18.21
LLA	F1	41.49	40.95	17.84
	F2	36.58	36.50	15.53
WLA	F1	73.94	85.59	30.21
	F2	51.70	52.37	22.74

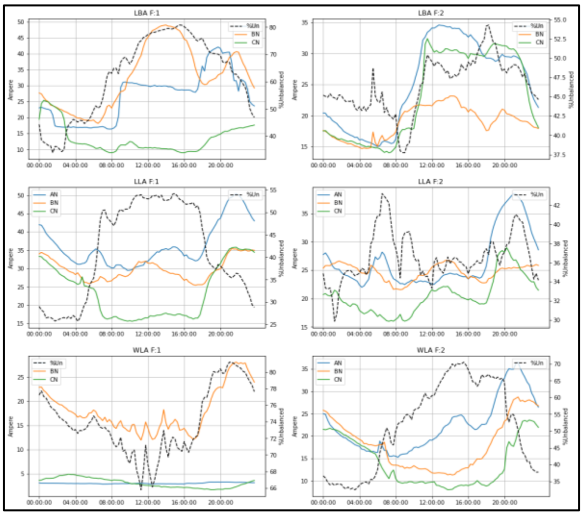

Figure 8. Daily Average Current (AHR rephasing).

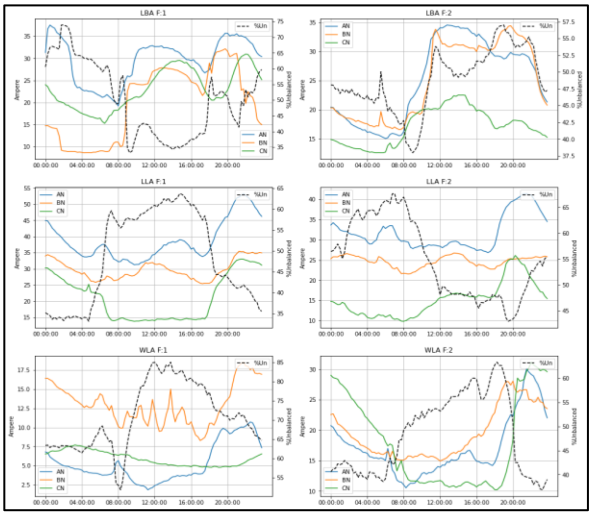

Figure 9. Daily Average Current (MCD rephasing).

4.4 MCD Phase-Swapping Results

After rephasing meters using the MCD algorithm from section 3.4, the daily average current supply results can be shown in Figure 9. It can be seen that unbalance percentages are less fluctuated than in Figure 7. Moreover, almost every mean and median value is also lower than values from Table 3, which the results in Table 5 can confirm.

Table 5. Unbalance Percentage (MCD rephasing).

Tr	Feeder	Average (%)	Median (%)	Standard Deviation
LBA	F1	50.45	51.00	20.78
	F2	48.84	49.85	17.40
LLA	F1	48.61	48.94	17.53
	F2	54.86	56.66	16.07
WLA	F1	70.94	75.13	24.23
	F2	48.43	48.33	19.78

4.5 Comparison Results

Since both rephasing results of AHR and MCD algorithms can significantly help reducing current unbalance percentages for all 3 transformers. Their performances should be compared to each other. In which, the best performer, with the lowest median value of the current unbalance percentage, will be selected as the proper algorithm to do rephasing for each transformer and feeder. Figure 10 presents the comparison results of both algorithms and also Table 6 shows the appropriate algorithm for each transformer and phase.

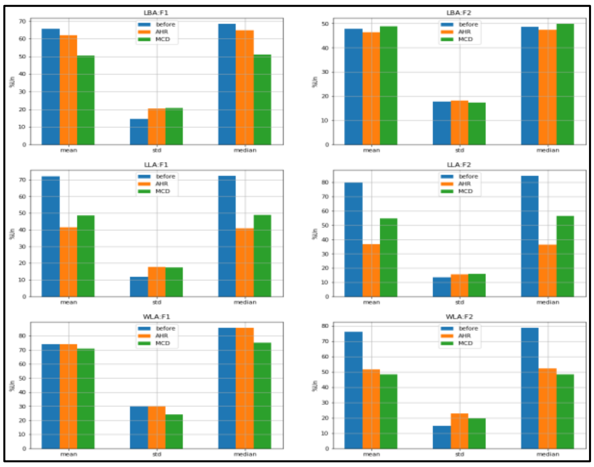

Figure 10. Performances Comparison Results.

Table 6. The number of Rephased Meters.

Tr	Feeder	Number of Rephased Meters		Proper Algorithm
		AHR	MCD	
LBA	F1	3	2	MCD
	F2	4	1	AHR
LLA	F1	6	3	AHR
	F2	6	3	AHR
WLA	F1	-	2	MCD
	F2	3	3	MCD

Figure 11 displays the number of meters by phase after applying the best algorithm for each transformer and feeder. It can be seen that number of meters has been changed from the number in Figure 5. However, the numbers are not that balance because meters are rephased based on their consumptions.

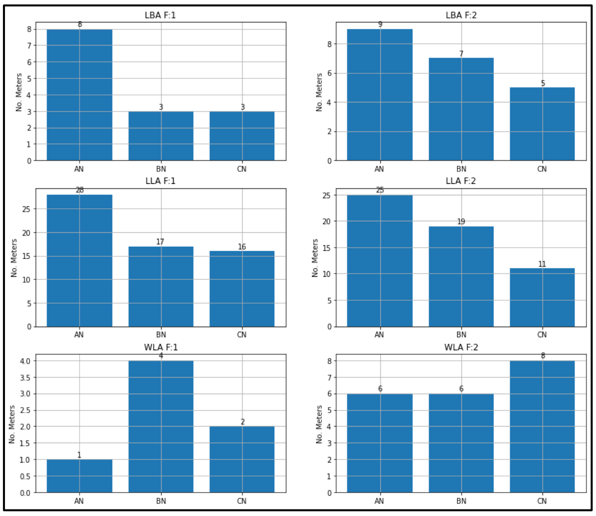

Figure 11. Number of Meters (after rephasing).

Moreover, considering only the potential of the unbalanced current reduction may not be enough because sufficient computational resources are needed to process both proposed algorithms, especially with these collected datasets, which are pretty large (Big Data) in terms of size and variety. Table 7 shows the overall computational times which are used by AHR and MCD algorithms. It can be seen that for AHR, it used an average of 71 seconds to provide rephasing order for each transformer and feeder, while MCD used only 1.25 seconds. This happens because they are working on the same objective but with different strategies.

Table 7. Overall Computational Time.

Algorithm	Overall Computational Time Usage (sec)
AHR	425.21 (avg. 71 sec / task)
MCD	7.52 (avg. 1.25 sec / task)

5. Conclusion

Utilizing smart meter data is important and needs to be done mainly by utilities (such as PEA) as investors of the systems. These consumption datasets can be analyzed to make them more useful and they can be more powerful by integrating with other related data sources. This study aims to reduce the current unbalance of distribution transformers by using AMI and GIS data. There are 2 proposed rephasing algorithms whose objective is to minimize the current unbalance percentage but with different strategies. The comparison results have shown that both of them are capable of reducing the current unbalance. Unfortunately, only the best algorithm is chosen to be the rephasing orders for each transformer and feeder. However, considering only the potential of current unbalanced reduction, sometimes not enough, especially when the datasets are large. Thus, computational resources, such as time usage, are needed to be considered. Utilities may have to trade-off between the performances and computational resources. Finally, the processes presented by this study can be implemented in the form of Web Applications to make them more usable for users. Figure 12 shows the QR code of the link to learn more about this Web Application developed by applying this study results.

Figure 12. Web Application Information QR-Code.

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