Study on DAS-Based Time Synchronization for Improving Reliability of Section Load Estimation

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Abstract

For effective distribution planning and operation, we need a reliable estimation of operation capacity. But it is difficult to ensure reliability due to the low accuracy of section load data, which is used as a basis in estimating the operation capacity. This paper discusses how to improve the accuracy of section load data by analyzing the existing method of estimating the section load, using statistical techniques to adjust the acquired data, and using the section load estimation algorithm to estimate the section 1oad based on the adjusted data.

Keywords : DAS, time synchronization, section load, estimation reliability

I. INTRODUCTION

It is essential to estimate the section load correctly considering the actual status of the line for distribution planning and operation. The existing method of estimating the section load data based on the distribution automation system is not correct and so it is only used for reference in operating the actual distribution systems. The data is not correct, because the useful voltage data is not acquired from the distribution switch and also because the current data is not time-synchronized at the switch and there are some missing data sections.

This paper discusses how to improve the accuracy of section load data by analyzing the existing method of using the distribution automation system to estimate the section load and identify problems, using statistical techniques to adjust the acquired data, and using the section load estimation algorithm to estimate the section load based on the adjusted data [1].

II. ANALYSIS ON EXISTING SYSTEM

The current data of the distribution automation system (DAS) is useful as DAS stores the system information and the data measured at the automation switch for a considerate period of time and also stores 15-minute maximum peak data. But, nevertheless, it is difficult to record the maximum peak time zones to estimate the section load on the power/load side during automation switching, as the times of storing the automation switching at each switch are irregular so that. This is called "current time desynchronization" in general. DAS contains the power factor data table, but it is not suitable to use it to estimate the peak power factor of the past cumulated time zones as it keeps the latest power factor values.

DAS has accumulated large current data of years from 14 headquarters, 176 offices and 10,763 DLs. To find out if the current data is used to estimate the section load, an one-minute time synchronizer was installed at each switch and the current data acquired from it was compared with 15-minute current data from RTU and DAS server current data.

Looking at the big picture, the DAS server data seems

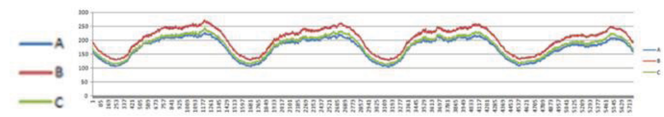

Fig. 1. 8.12-8.15 one-minute time synchronization data at Yeonmugan

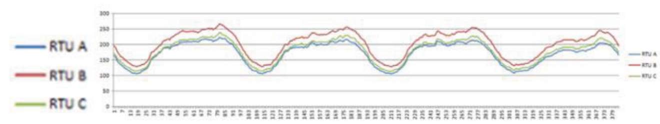

Fig. 2. 8.12-8.15 15-minute time RTU data at Yeonmu DL

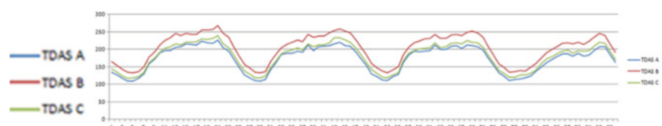

Fig. 3. One-hour DAS server data at Yeonmu DL

useful as it has the same flow with the time synchronizer's measured data and RTU's 15-minute data. To estimate the section load and regular operation capacity, use the current data to acquire the maximum peak. Both SOMAS and DAS have the maximum peak data for the current. SOMAS gets the current measurements every two minutes, calculates the average value every one year and stores the largest maximum peak time zone and maximum peak current average value. The two-minute data is stored for 45 days before being discarded.

DAS measures the current every 15 minutes and, when it discovers the maximum peak, it stores the maximum peak time and maximum peak current value which is sent to the server per one hour. The current is measured when requested by the user. If the current is at the maximum peak at this time, the time and maximum peak current value are sent to the server.

In summary, SOMAS has the current value of one-hour average time zone as the peak value while DAS has the maximum peak time and current value. It is believed that the current value of DAS is closer to the maximum peak.

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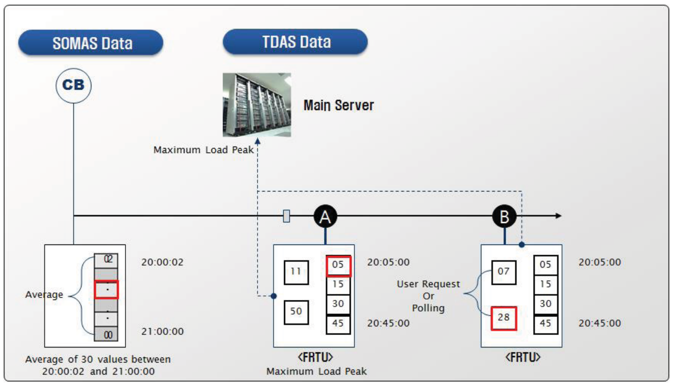
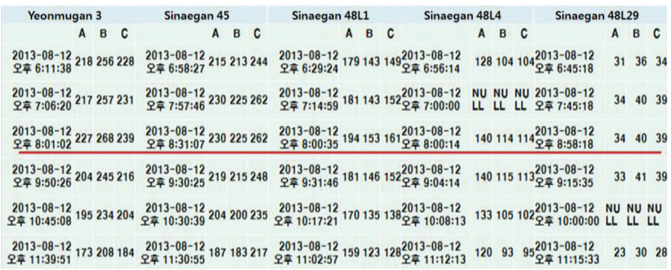


Fig. 4. Maximum peak values comparison between SOMAS and DAS



Yeonmugan 3	A	B	C	Sinaegan 45	A	B	C	Sinaegan 48L1	A	B	C	Sinaegan 48L4	A	B	C	Sinaegan 48L29	A	B	C
2013-08-12 오후 6:11:38	218	256	228	2013-08-12 오후 6:58:27	215	213	244	2013-08-12 오후 6:29:24	179	143	149	2013-08-12 오후 6:56:14	128	104	104	2013-08-12 오후 6:45:18	31	36	34
2013-08-12 오후 7:06:20	217	257	231	2013-08-12 오후 7:57:46	230	225	262	2013-08-12 오후 7:14:59	181	143	152	2013-08-12 오후 7:00:00	NULL	NULL	NULL	2013-08-12 오후 7:45:18	34	40	39
2013-08-12 오후 8:01:02	227	268	239	2013-08-12 오후 8:31:07	230	225	262	2013-08-12 오후 8:00:35	194	153	161	2013-08-12 오후 8:00:14	140	114	114	2013-08-12 오후 8:58:18	34	40	39
2013-08-12 오후 9:50:26	204	245	216	2013-08-12 오후 9:30:25	219	215	248	2013-08-12 오후 9:31:46	181	146	152	2013-08-12 오후 9:04:14	140	115	113	2013-08-12 오후 9:15:35	33	41	39
2013-08-12 오후 10:45:08	195	234	204	2013-08-12 오후 10:30:39	204	200	235	2013-08-12 오후 10:17:21	170	135	138	2013-08-12 오후 10:08:13	133	105	102	2013-08-12 오후 10:00:00	NULL	NULL	NULL
2013-08-12 오후 11:39:51	173	208	184	2013-08-12 오후 11:30:55	187	183	217	2013-08-12 오후 11:02:57	159	123	128	2013-08-12 오후 11:12:13	120	93	95	2013-08-12 오후 11:15:33	23	30	28

Fig. 5. DAS Current Data

There are about one hour difference between the maximum load peak time zones of SOMAS and DAS. SOMAS starts at 20:00:02, measures every two minutes and stores the average value at 21:00:00, while DAS stores the measuring times. Thus about one-hour difference is generated.

DAS generates 24 pieces of current data per day at each automatic switch. It means that one-year operation generates more than 600 million pieces of current data (70,000 switches x 365 days x 24 pieces) A method to find out the maximum peak from them should be provided. The current flows more on the power side if the load side knees the electric power. If we assume that the peak time is when the first automatic switch installed at DL is at peak, we can find the largest value of a desired range.

III. CURRENT DATA ISSUES AND SOLUTIONS

Though, as shown in Fig. 4, the current data may seem to be nice to be used, but DAS current data has irregular storing times as it measures the current based on the automatic switch. As shown in Fig. 6, if the power-side current is subtracted from the load side, the difference becomes larger.

The maximum peak value of Yeonmugan 3 per day, the first automatic switch of Yeonmu DL, is found at 8:01:02 PM when the sum of A, B and C phases are the largest. But the next automatic switch, Sinaegan 45, has the current value measured at 8:31:07 PM. The times are different and the section load is not correct when the power-side current is subtracted. To acquire the correct section load, the Sinaegan 45's current value should be adjusted according to 8:01:02.

The current data should be adjusted by the time-series analysis. The data measured consecutively over time is called "time series". The examples of time series includes gross national production, price index, composite stock price index,

Table 1. Aitken repetitive interpolation method

Name of automatic switch	[kW]	Adjusted Current [A]	Starter Measured current	Difference (Absolute value)	Missing Rate
Yeonmugan 3 (bottom)	256.8	244.7	243	1.7	0%
Sinaegan 45 (top)	2471.3	239	234.3	4.7	33%
Sinaegan 48L1	1654.3	169.3	165	4.3	100%
Sinaegan 48L4	3005.9	122.7	122.3	0.4	0%
Sinaegan 48L29	1326	37.7	38.7	1	23%
Total / (average)	8735.2	1058.1	1046.3	(2.3)	29%

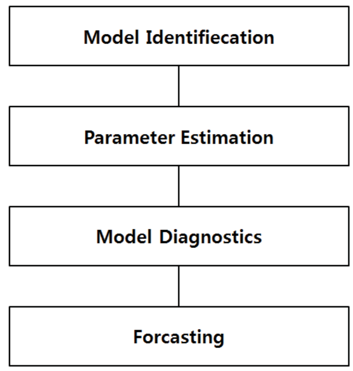


Fig. 6. Time Series Analysis Flow Chart

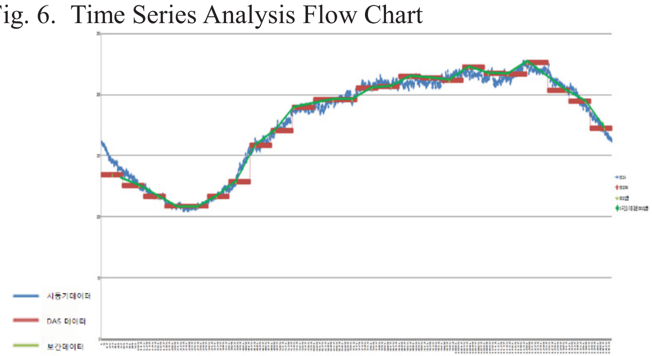


Fig. 7. Time series analysis by Excel

rainfall, etc. The purpose of time series analysis is to understand and modelize the probabilistic system that generates time series and to use the past measurements to forecast the future values and to provide basic information for the planning of future policies.

The process of time series analysis, as shown in Fig. 7, includes model identification, parameter estimation, model diagnostics and forecasting. Model identification uses time series (observed values) to identify a suitable model shape. Parameter estimation uses observed values to estimate the parameters of the identified model. Model diagnostics verifies that the selected model explains the time series system successfully. If this step is meaningful, the model is confirmed. If not, the process returns to model identification. Forecasting uses the confirmed model to generate the future values.

To adjust the time of current data, Excel, Aitken repetition, and intervaled-linear techniques were applied. Excel can carry out the time series analysis but cannot provide a value that is adjusted according to a certain time (peak time). It cannot

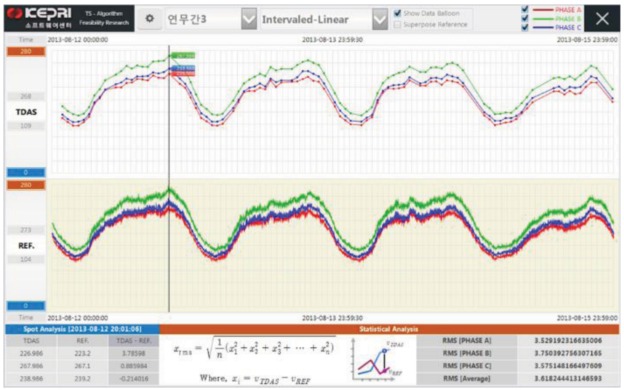


Fig. 8. Intervaled Linear technique for Yeonmugan 3, Yeonmu DL

$$g(x) = \frac{f(x_{i+1}) - f(x_i)}{x_{i+1} - x_i}(x - x_i) + f(x_i)$$

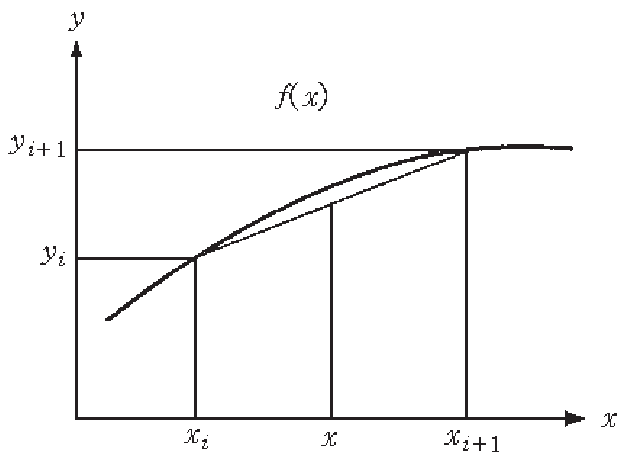


Fig. 9. Linear Interpolation Technique

acquire the correct values.

The Aitken repetition technique was used to acquire the adjusted current value. This technique is only applicable when there is no missing data on the current or previous day. The difference is about 2.3.

The Intervaled-Linear technique was applied and DAS server data and starter measured data were compared and verified. Yeonmugan 3, Sinaegan 45, Sinaegan 48L1, Sinaegan 48L14 , and Sinaegan 48L14 were adjusted in the order of automatic switch installation for Yeonmu DL according to the measuring time of Yeonmugan 3 to estimate the current value.

The estimated value is displayed at the top of the screen and the starter value is displayed at the bottom. The difference between the estimated value and starter value is displayed at the bottom-left corner to show that there is almost no difference. The total difference is about 1.46. According to the analysis results, the Intervaled Linear, which showed the smallest difference, will be applied [2].

For the current measured at the automatic switch, its history data is recorded every hour. The history data of the measured current should be adjusted as the measurement time at the automatic switch is irregular and the automatic switches are not synchronized.

The maximum load of the past one year is set to the section load. For this, the time when the first automatic switch from CB

Table 2. Data missing rate at starter-measure DL

DL Name	Number of switches	Number of Days	Number of Points	Server Stored Pieces	Missing Rate
Yeonmu	5	4	480	480	0%
Buksu	3	4	288	192	33%
Sanseong	5	4	480	0	100%
Jukdang	4	7	672	672	0%
Iseo	4	5	480	368	23%
Total			2400	1712	29%

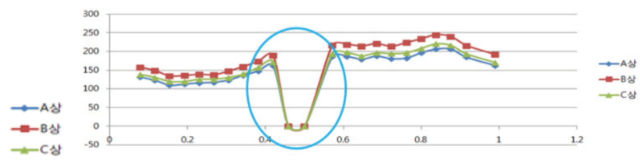


Fig. 10. Data Missing of DAS

is the largest is used as the reference time. If the reference time for the first automatic switch is set, other automatic switches uses the current value for this reference time.

By marking the measured current values as dots and drawing a line between them, we can forecast the value for a certain time. To forecast the current values for a certain time, the linear interpolation determines the value linearly based on the straight line between two points. If two points, x_1 and x_2, have data values, $f(x_1)$ and $f(x_2)$, respectively, the data value $g(x)$ at a point, x ($x_1 \leq x \leq x_2$), between x_1 and x_2 is estimated as follows when the linear interpolation is used.

To use time series analysis to interpolate the current data for estimation, we need the data of previous day or current day (24 pieces of data of a day). If there is missing data in the referenced data, we should use the past data and statistical techniques to estimate current data with minimized difference [3].

The data stored in the server is sometimes missing due to DAS communication error or malfunction of DAS schedule program.

24 pieces of current data per automatic switch per day should be stored. The number of points that should a measured section DL should have is as follows if estimated by the formula of number of switches × number of days × 24. However, the number of the points stored in the DAS server are about 29% missing.

The solution for this problem is to use statistical data estimation or to use numerical data interpolation to adjust the missing section data. For instance, we can use various data such as season, month, week, day to make the first estimation. We may add the weighted value to the recent data. After the first estimation, use the numerical data interpolation to apply various numerical interpolation techniques including linear interpolation for the second adjustment [2].

IV. SECTION LOAD ESTIMATING METHODS

A. Process of Section Load Estimation Algorithm

The current data is measured and stored by DAS, but the voltage data should be forecasted as it is not provided. To forecast the voltage data to estimate current section load, a calculation algorithm (Forward-Backward Sweep Method) was

Table 3. Section Load Estimation Results Verification

DL Name	Variables	Off-DAS	Results	Difference	Difference Rate
Buksu	Voltage[pu]	0.99394[pu]	0.99474[pu]	0.0008[pu]	0.08%
	Voltage Drop[pu]	0.99255[pu]	0.99314[pu]	0.0006[pu]	0.06%
	Active Power[kW]	6702.6[kW]	6712.4[kW]	9.8[kW]	0.15%
Yeonmu	Voltage[pu]	0.99719[pu]	0.99768[pu]	0.0005[pu]	0.05%
	Voltage Drop[pu]	0.98561[pu]	0.98592[pu]	0.0031[pu]	0.03%
	Active Power[kW]	8436.3[kW]	8460.3[kW]	24.0[kW]	0.28%
Jukdang	Voltage[pu]	0.97676[pu]	0.97712[pu]	0.0004[pu]	0.04%
	Voltage Drop[pu]	0.97440[pu]	0.97474[pu]	0.0034[pu]	0.03%
	Active Power[kW]	4307.4[kW]	4355.1[kW]	47.7[kW]	1.10%
Iseo	Voltage[pu]	0.98124[pu]	0.98400[pu]	0.0028[pu]	0.28%
	Voltage Drop[pu]	0.98112[pu]	0.98348[pu]	0.0024[pu]	0.24%
	Active Power[kW]	5871.0[kW]	5818.7[kW]	52.3[kW]	0.89%

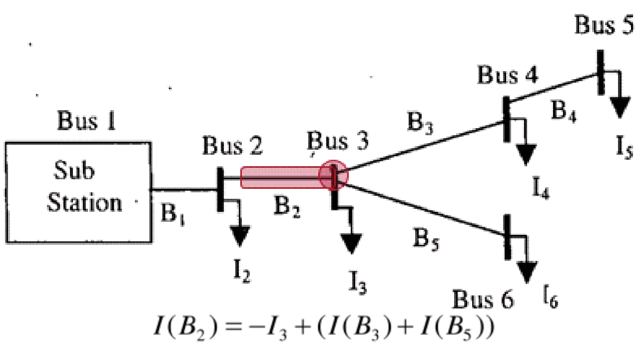


Fig. 11. Backward-Forward Substitution technique

used. As shown in the Fig. 11, the Backward and Forward Substitution techniques are applied to the radialized lines.

1) Backward Substitution

- It is used to calculate the branch's current.
- The end branch current at the end load is the same as the injected current at the corresponding end nod.
- Track the branch current in the backward direction from the end branch current, while using KCL (Kirchhoff's rules) to calculate the branch current.

$$\begin{bmatrix} I_a(m) \\ I_b(m) \\ I_c(m) \end{bmatrix} = -\begin{bmatrix} i_{Ia} \\ i_{Ib} \\ i_{Ic} \end{bmatrix} + \sum_{p \in M} \begin{bmatrix} I_{ap} \\ I_{bp} \\ I_{cp} \end{bmatrix}$$

- Here, $I_a(m)$, $I_b(m)$, and $I_c(m)$ are the currents of branch m.
- i_{Ia}, i_{Ib}, and i_{Ic} are the equivalent injected current at the branch m's child node (i).
- m means the branch connected to the branch m's child node.

2) Forward Substitution

- Swing parent line's voltage size should be set to the designated value.
- Track the branch current in the forward direction [source □ end load], while using KVL (Kirchhoff's rules) to calculate the node voltage as in the following:

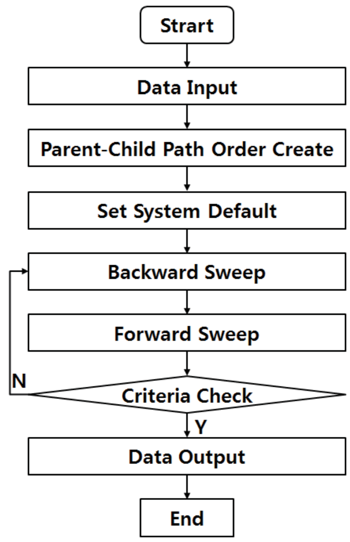


Fig. 12. Section load estimation algorithm execution flow chart

$$\begin{bmatrix} v_a(i) \\ v_b(i) \\ v_c(i) \end{bmatrix} = \begin{bmatrix} v_a(j) \\ v_b(j) \\ v_c(j) \end{bmatrix} - \begin{bmatrix} z_{aa} z_{ab} z_{ac} \\ z_{ba} z_{bb} z_{bc} \\ z_{ca} z_{cb} z_{cc} \end{bmatrix} \begin{bmatrix} l_a(m) \\ l_b(m) \\ l_c(m) \end{bmatrix}$$

- Here, the branch current calculated in Backward Substitution was used in the calculation.
- i and j are the nodes of child and parent, respectively.
- The calculated voltage value is used in current calculation in the next Backward Substitution stage [4].

3) Section Load Estimation

- If the value falls in the allowed range, stop the process. If not, repeat the step 2 and 3.
- Multiply the voltage values acquired by Backward-Forward substitution technique and the current value acquired by the interpolation technique to estimate the section load [MVA] [3].

B. Section Load Estimation Algorithm Results Verification

The results acquired by using the load current measured at four DLs were compared with the off-DAS program. Input the measured switch current and impedance to execute estimation [6].

As shown in the above results table, it is confirmed that the difference rate between four DLs and voltage drop is less than 1%. This shows that the section load estimation method proposed here is reliable to a certain degree.

V. CONCLUSION

To estimate the section load correctly, the current and voltage data at the line switch should be correct. This paper studied how to resolve the current data desynchronization issue and solved the problem by using a statistical adjustment based on the time zone when the maximum peak current is generated at the first switch from CB. As the statistical adjustment method, the linear interpolation technique that generates the minimized difference from the actually-measured data. For the adjustment, the missing data was also estimated. It was estimated first using the existing statistic data in the same time zone and the rest was estimated again by the second adjustment. Unlike the current data, there was no available voltage data for DAS. It was forecasted by the section load estimate algorithm. The previously adjusted current data was used to acquire the voltage data for each line section. These acquired voltage/current values were used to acquire the load amount for each section.

Currently this study is being developed as a distribution line capacity program to estimate the section load and show the key diagrams on the web. Using the section load data, the results of this study, we are developing a program for the estimation of distribution connection power and regular operation capacity. We plan to test this system on the site to verify the reliability of the system and link it to the next-generation electric power trade information system in the future.

REFERENCES

[1] "Establishment of Improved Operation Standards Using Electricity Distribution System Information", R&D Project Plan, Byeong-seong Lee, 1-4, 2013

[2] "R&D Execution Details and Results", Interim Report, In-tae Lee, 3-13, 2014

[3] "Section Load Estimation Verification Report", Quarterly Report, Mancheol Sin, 2-3, 2014

[4] D.Thukaram, "A robust three phase power flow algorithm for radial distribution systems", Electric Power Systems Research 50(1999) 227-236

[5] Shohreh Abolmasoumi, "A method for calculating interval linear system", Journal of Mathematics and Computer Science (2014), 193-204

[6] "Electricity Distribution Line Section Load Algorithm Verification Results Report", In-tae Lee, 2014