

Analysis of Deviation Values of Electrical Energy Measuring and Limiting Instruments in the Indirect Measuring System of PT PLN UP3 Belitung

Syafira Saharani, Muhammad Erpandi Dalimunthe, Parlin Siagian

Abstract

This study aims to analyze the deviation value of the Measuring and Limiting Device (APP) in the indirect measurement system of medium voltage customers at PT PLN (Persero) UP3 Belitung. Measurements were carried out using two approaches, namely manually using the WS2330 Portable Standard Meter and digitally through the PLN Daily Performance Monitoring (DPM) system. Tests were conducted on industrial customers, namely PT Tommy Utama, PT Timah TBK, and PT Hafidar Sukses Nusantara. The measurement results showed a significant decrease in the deviation value after technical repair actions. Before the repair, the highest deviation value of 3.2% occurred in PT Timah TBK customers. The average deviation value after the repair was within the tolerance limit of SPLN 34-2:2012 ($\pm 0.5\%$ – 1%). In addition, the measurement data were used to build a Random Forest Classifier model to automatically classify APP conditions based on the WS2330 and DPM output parameters. The simulation results showed an accuracy of 83.8% indicating the great potential of applying machine learning in supporting the early detection system for APP deviations. This study recommends the development of a Hybrid Monitoring System based on the integration of field and digital data to improve the reliability of the measurement system at PLN.

Keywords: APP, Measurement Deviation, PLN, Machine Learning, WS2330

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Introduction

Electrical energy is one of the fundamental necessities of modern society, playing a crucial role in supporting economic, social, and technological development [1], [2]. As the national electricity provider, PT PLN (Persero) is responsible for ensuring reliable electricity distribution and accurate recording of energy consumption. This recording process is carried out through the Measuring and Limiting Device (Alat Pengukur dan Pembatas, APP), which serves as the basis for electricity energy transactions between customers and PLN [3].

Accurate APP performance not only ensures fairness for customers in billing processes but also directly contributes to the reduction of energy losses, which represent one of PLN's key performance indicators [4]. Deviations or inaccuracies in APP measurements lead to discrepancies between actual energy consumption and recorded values, potentially resulting in financial losses for both PLN and customers [5]. On a broader scale, undetected and systematic APP deviations may undermine PLN's operational accountability and affect tariff policies as well as long-term energy planning.

Medium-voltage (MV) customer metering systems generally employ indirect measurement methods involving Current Transformers (CTs) and Potential Transformers (PTs) [6]. Although this approach is more practical and safer for high-capacity customers, the use of CTs and PTs introduces additional sources of error within the measurement system [7]. Several factors may contribute to APP deviation, including CT/PT failures that alter current or voltage ratios, installation or wiring errors that lead to measurement mismatches, burdens that do not comply with SPLN standards, and environmental conditions such as high humidity, flooded cubicles, or exposure to extreme temperatures.

Previous studies have emphasized the importance of APP accuracy and the impact of CT/PT errors on measurement results [8], [9]. However, most existing research remains limited to manual analysis using calibration instruments and has not yet integrated data-driven analytical approaches to support early detection of measurement deviations [10], [11].

Advancements in digital technology have enabled real-time collection of customer energy consumption data through Automatic Meter Reading (AMR) systems such as Amicon. The generated data include load profiles, voltage, current, power factor, and event logs, which have significant potential for further analysis to detect anomalies or APP deviations. Nevertheless, in practice, these data have not been optimally utilized for predictive or classification purposes [12].

On the other hand, Machine Learning (ML) methods have been widely applied in power systems, including load forecasting, fault detection, and reliability prediction of distribution networks [13]. The application of ML for detecting APP measurement deviations remains relatively limited, despite its substantial potential to enhance PLN's operational efficiency [14].

Along with the ongoing digitalization of power systems, data from Daily Performance Monitoring (DPM) or Amicon (Automatic Meter Reading) platforms can be leveraged for automatic deviation detection. By employing Machine Learning techniques, historical customer energy consumption data can be analyzed to identify deviation patterns (anomalies) and classify APP operating conditions.

The research problems addressed in this study are formulated as follows:

1. To determine the calculation and measurement of deviation values in the Measuring and Limiting Device (Alat Pengukur dan Pembatas, APP) within an indirect metering system.
2. To evaluate APP performance through field measurements using the WS2330 Portable Standard Meter and digital data analysis obtained from the Daily Performance Monitoring (DPM) system.
3. To identify the causes of measurement errors in APP installed for medium-voltage customers at PT PLN (Persero) UP3 Belitung.

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Based on these problems, this study aims to analyze the calculation and measurement of APP deviation values in an indirect metering system, to conduct both manual (WS2330-based) and digital (DPM-based) APP testing in order to evaluate measurement accuracy, to identify the technical and data-related factors contributing to APP measurement errors, to apply a Random Forest Classifier algorithm for automatic classification of APP operating conditions, and to develop a Hybrid Monitoring System concept as an early detection mechanism for APP deviation at PLN. Consequently, this research provides a practical contribution to PT PLN (Persero) in enhancing the reliability of its electrical energy metering system.

Literature Review

1.1 Measuring and Limiting Device (APP)

The Measuring and Limiting Device (Alat Pengukur dan Pembatas, APP) is the primary equipment used by PT PLN (Persero) to record customer electrical energy consumption. The APP consists of a kWh meter, a power limiter, a Current Transformer (CT), and a Potential Transformer (PT). For customers with high power demand or medium-voltage levels, an indirect metering system is applied, which relies on CTs and PTs to enable safe measurement of current and voltage values [17].Sistem Pengukuran Tidak Langsung

1.2 Indirect Metering System

For medium-voltage (MV) customers, an indirect metering system is employed because high current and voltage levels cannot be measured directly by energy meters. Therefore, CTs and PTs are used to step down current and voltage to safe levels for metering equipment. However, mismatched CT/PT ratios, wiring errors, and environmental conditions such as temperature and humidity may introduce measurement deviations. CT errors in the range of 2–3% can significantly affect kWh measurement results. Consequently, routine APP testing is required to ensure that measurement accuracy remains in compliance with SPLN standards.

1.3 APP Measurement Deviation

Measurement deviation refers to the difference between the APP measurement results and the actual electrical energy consumed. The primary causes of deviation include CT/PT failures—such as CT core saturation or winding damage, which alter the current ratio delivered to the meter—installation or wiring errors, including phase or polarity mismatches that may lead to negative or inaccurate power calculations, non-compliant burden conditions in which excessive secondary loads increase measurement error, and adverse environmental conditions such as high humidity, extreme temperatures, or flooded cubicles that affect insulation performance and measurement accuracy. CT errors can impact measurement accuracy by several percentage points, leading to significant implications for energy billing values [6]. Meanwhile, the WS2330 Portable Standard Meter manual explains that portable testing can directly detect kWh and CT deviation errors in the field, thereby supporting technical inspection of APP installations [12].

1.4 APP Testing Using the WS2330 Instrument

The WS2330 Portable Standard Meter is a field testing instrument used by PLN to directly evaluate the accuracy of kWh meters, CTs, and PTs. The WS2330 is capable of detecting installation errors and CT/PT mismatches with high accuracy. The testing procedure includes measurements of current, voltage, power, and power factor, which are then compared against

standard reference values. Despite its effectiveness, this method has limitations, as it is manual in nature and not performed continuously.

1.5 Application of Machine Learning in Metering Systems

Advances in Machine Learning (ML) have created significant opportunities for improving power system management. Previous studies [15] have demonstrated that ML models such as Random Forest and Decision Tree algorithms can identify system fault patterns with high accuracy. In this study, a Random Forest Classifier algorithm is employed to classify APP operating conditions based on PLN's Daily Performance Monitoring (DPM) data into three categories: Normal, Minor Deviation, and Major Deviation [18], [19].

Research Methodology

The research was conducted within the operational area of PT PLN (Persero) UP3 Belitung. Data were collected using two primary methods:

1. Field measurements using the WS2330 Portable Standard Meter on customers PT Tommy Utama, PT Timah Tbk, and PT Hafidar Sukses Nusantara.
2. Digital data obtained from PLN's Daily Performance Monitoring (DPM) system, including parameters of active energy, load current, voltage, and power factor.

The research stages consisted of the following steps:

1. A literature review covering SPLN 34-2:2012 standards and the fundamental theory of indirect metering systems.
2. Collection of field measurement data and digital monitoring data.
3. Data preprocessing, including the removal of missing values, time alignment, and data verification.
4. Deviation calculation using the following equation:

$$\text{Deviation (\%)} = \frac{E_{\text{actual}} - E_{\text{measured}}}{E_{\text{measured}}} \times 100$$

5. Classification of APP operating conditions into three categories: Normal (<0.5%), Minor Deviation (0.5–1%), and Major Deviation (>1%).
6. Implementation of the Random Forest Classifier algorithm using combined WS2330 and DPM measurement data, with an 80% training set and 20% testing set split.
7. Validation of the classification results using accuracy as the evaluation metric

The research workflow is illustrated in Figure 1, encompassing the stages of literature review, data collection, deviation analysis, implementation of the machine learning model, and result validation.

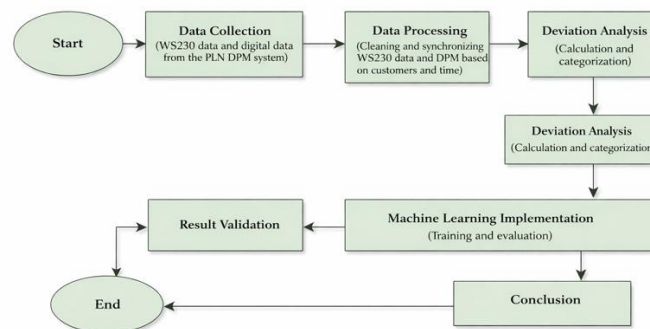


Figure 1. Research Workflow Diagram.

Results

Test Results

The study was conducted within the operational area of PT PLN (Persero) UP3 Belitung, involving three medium-voltage customers: PT Tommy Utama, PT Timah Tbk, and PT Hafidar Sukses Nusantara.

1. PT Tommy U***

a. Monthly kWh Consumption Analysis (DPM Monitoring)

The DPM monitoring results indicate that this customer experienced a 39% decrease in monthly kWh consumption compared to the previous six months. The kWh consumption data are presented in Figure 2.

NAMA	TARIF	DAYA	PEM KWH (MON DPM)											
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AGO	SEPT	OCT	NOV	DES
PT MEHARA ***	3	277000	32940	31200	29000	24610	78220	78760	75200	75200	75200	75200	75200	75200
SWP KERNEL ***	3	173000	32940	31200	29000	24610	78220	78760	75200	75200	75200	75200	75200	75200
PT KURMA ***	3	111000	17920	15820	18100	15260	19610	17510	20210	20210	20210	20210	20210	20210
PT INDOMAKJUR ***	3	111000	15270	17180	11300	8730	12910	16830	17180	17180	17180	17180	17180	17180
PT TIMAH P ***	3	305000	16800	14100	17440	11260	26760	14480	16810	16810	16810	16810	16810	16810
PT HAFIDAR ***	3	555000	10804	11080	15910	13672	84120	98520	136520	136520	136520	136520	136520	136520
RSU ***	3	345000	11204	11880	12032	11476	13084	13288	135304	135304	135304	135304	135304	135304
PT TIMAH ***	3	111000	8384	10128	12372	11132	28384	103744	50432	50432	50432	50432	50432	50432
PT DPM ***	3	111000	28808	17360	15456	15456	21280	170704	90784	90784	90784	90784	90784	90784
PT WIDA ***	3	555000	118496	59152	151784	181080	211944	73912	81048	81048	81048	81048	81048	81048
PABRIK ***	3	555000	0	10304	88800	61384	76416	78416	68224	68224	68224	68224	68224	68224
PT BELITUNG ***	3	111000	124064	118564	101516	32768	57904	53192	48864	48864	48864	48864	48864	48864
PT SWP ***	3	555000	32800	25176	27712	30160	35880	38824	41672	41672	41672	41672	41672	41672
CV BELTIM ***	3	680000	83800	98480	123280	39936	4720	12784	32120	32120	32120	32120	32120	32120
POMPA PT ***	3	345000	32408	23728	26780	14884	27036	27544	28864	28864	28864	28864	28864	28864
PT ALFARO ***	3	111000	0	0	0	0	0	132	4560	4560	4560	4560	4560	4560
PT DARS ***	3	240000	8000	8140	8800	7140	8180	7980	7480	7480	7480	7480	7480	7480
PT ANTASENA ***	3	345000	0	0	0	0	0	0	1480	1480	1480	1480	1480	1480
PROCESING ***	3	240000	0	0	0	0	0	0	1096	1096	1096	1096	1096	1096
PT KARYA ***	3	111000	0	0	0	0	0	0	0	0	0	0	0	0

Figure 2. Monthly kWh Consumption (DPM Monitoring) of PT Tommy U* **

b. AMR Reading Inspection Using the Amicon Application

Based on the AMR readings obtained through the Amicon application, an anomaly was identified in the secondary current of the kWh meter, where the recorded secondary current value was zero (0). The AMR reading results for customer PT Tommy* are presented in Figure 3.

Area	Point	Meter	Date	V1	V2	V3	I1	I2	I3	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40	W41	W42	W43	W44	W45	W46	W47	W48	W49	W50	W51	W52	W53	W54	W55	W56	W57	W58	W59	W60	W61	W62	W63	W64	W65	W66	W67	W68	W69	W70	W71	W72	W73	W74	W75	W76	W77	W78	W79	W80	W81	W82	W83	W84	W85	W86	W87	W88	W89	W90	W91	W92	W93	W94	W95	W96	W97	W98	W99	W100	W101	W102	W103	W104	W105	W106	W107	W108	W109	W110	W111	W112	W113	W114	W115	W116	W117	W118	W119	W120	W121	W122	W123	W124	W125	W126	W127	W128	W129	W130	W131	W132	W133	W134	W135	W136	W137	W138	W139	W140	W141	W142	W143	W144	W145	W146	W147	W148	W149	W150	W151	W152	W153	W154	W155	W156	W157	W158	W159	W160	W161	W162	W163	W164	W165	W166	W167	W168	W169	W170	W171	W172	W173	W174	W175	W176	W177	W178	W179	W180	W181	W182	W183	W184	W185	W186	W187	W188	W189	W190	W191	W192	W193	W194	W195	W196	W197	W198	W199	W200	W201	W202	W203	W204	W205	W206	W207	W208	W209	W210	W211	W212	W213	W214	W215	W216	W217	W218	W219	W220	W221	W222	W223	W224	W225	W226	W227	W228	W229	W230	W231	W232	W233	W234	W235	W236	W237	W238	W239	W240	W241	W242	W243	W244	W245	W246	W247	W248	W249	W250	W251	W252	W253	W254	W255	W256	W257	W258	W259	W260	W261	W262	W263	W264	W265	W266	W267	W268	W269	W270	W271	W272	W273	W274	W275	W276	W277	W278	W279	W280	W281	W282	W283	W284	W285	W286	W287	W288	W289	W290	W291	W292	W293	W294	W295	W296	W297	W298	W299	W300	W301	W302	W303	W304	W305	W306	W307	W308	W309	W310	W311	W312	W313	W314	W315	W316	W317	W318	W319	W320	W321	W322	W323	W324	W325	W326	W327	W328	W329	W330	W331	W332	W333	W334	W335	W336	W337	W338	W339	W340	W341	W342	W343	W344	W345	W346	W347	W348	W349	W350	W351	W352	W353	W354	W355	W356	W357	W358	W359	W360	W361	W362	W363	W364	W365	W366	W367	W368	W369	W370	W371	W372	W373	W374	W375	W376	W377	W378	W379	W380	W381	W382	W383	W384	W385	W386	W387	W388	W389	W390	W391	W392	W393	W394	W395	W396	W397	W398	W399	W400	W401	W402	W403	W404	W405	W406	W407	W408	W409	W410	W411	W412	W413	W414	W415	W416	W417	W418	W419	W420	W421	W422	W423	W424	W425	W426	W427	W428	W429	W430	W431	W432	W433	W434	W435	W436	W437	W438	W439	W440	W441	W442	W443	W444	W445	W446	W447	W448	W449	W450	W451	W452	W453	W454	W455	W456	W457	W458	W459	W460	W461	W462	W463	W464	W465	W466	W467	W468	W469	W470	W471	W472	W473	W474	W475	W476	W477	W478	W479	W480	W481	W482	W483	W484	W485	W486	W487	W488	W489	W490	W491	W492	W493	W494	W495	W496	W497	W498	W499	W500	W501	W502	W503	W504	W505	W506	W507	W508	W509	W510	W511	W512	W513	W514	W515	W516	W517	W518	W519	W520	W521	W522	W523	W524	W525	W526	W527	W528	W529	W530	W531	W532	W533	W534	W535	W536	W537	W538	W539	W540	W541	W542	W543	W544	W545	W546	W547	W548	W549	W550	W551	W552	W553	W554	W555	W556	W557	W558	W559	W560	W561	W562	W563	W564	W565	W566	W567	W568	W569	W570	W571	W572	W573	W574	W575	W576	W577	W578	W579	W580	W581	W582	W583	W584	W585	W586	W587	W588	W589	W590	W591	W592	W593	W594	W595	W596	W597	W598	W599	W600	W601	W602	W603	W604	W605	W606	W607	W608	W609	W610	W611	W612	W613	W614	W615	W616	W617	W618	W619	W620	W621	W622	W623	W624	W625	W626	W627	W628	W629	W630	W631	W632	W633	W634	W635	W636	W637	W638	W639	W640	W641	W642	W643	W644	W645	W646	W647	W648	W649	W650	W651	W652	W653	W654	W655	W656	W657	W658	W659	W660	W661	W662	W663	W664	W665	W666	W667	W668	W669	W670	W671	W672	W673	W674	W675	W676	W677	W678	W679	W680	W681	W682	W683	W684	W685	W686	W687	W688	W689	W690	W691	W692	W693	W694	W695	W696	W697	W698	W699	W700	W701	W702	W703	W704	W705	W706	W707	W708	W709	W710	W711	W712	W713	W714	W715	W716	W717	W718	W719	W720	W721	W722	W723	W724	W725	W726	W727	W728	W729	W730	W731	W732	W733	W734	W735	W736	W737	W738	W739	W740	W741	W742	W743	W744	W745	W746	W747	W748	W749	W750	W751	W752	W753	W754	W755	W756	W757	W758	W759	W760	W761	W762	W763	W764	W765	W766	W767	W768	W769	W770	W771	W772	W773	W774	W775	W776	W777	W778	W779	W780	W781	W782	W783	W784	W785	W786	W787	W788	W789	W790	W791	W792	W793	W794	W795	W796	W797	W798	W799	W800	W801	W802	W803	W804	W805	W806	W807	W808	W809	W810	W811	W812	W813	W814	W815	W816	W817	W818	W819	W820	W821	W822	W823	W824	W825	W826	W827	W828	W829	W830	W831	W832	W833	W834	W835	W836	W837	W838	W839	W840	W841	W842	W843	W844	W845	W846	W847	W848	W849	W850	W851	W852	W853	W854	W855	W856	W857	W858	W859	W860	W861	W862	W863	W864	W865	W866	W867	W868	W869	W870	W871	W872	W873	W874	W875	W876	W877	W878	W879	W880	W881	W882	W883	W884	W885	W886	W887	W888	W889	W890	W891	W892	W893	W894	W895	W896	W897	W898	W899	W900	W901	W902	W903	W904	W905	W906	W907	W908	W909	W910	W911	W912	W913	W914	W915	W916	W917	W918	W919	W920	W921	W922	W923	W924	W925	W926	W927	W928	W929	W930	W931	W932	W933	W934	W935	W936	W937	W938	W939	W940	W941	W942	W943	W944	W945	W946	W947	W948	W949	W950	W951	W952	W953	W954	W955	W956	W957	W958	W959	W960	W961	W962	W963	W964	W965	W966	W967	W968	W969	W970	W971	W972	W973	W974	W975	W976	W977	W978	W979	W980	W981	W982	W983	W984	W985	W986	W987	W988	W989	W990	W991	W992	W993	W994	W995	W996	W997	W998	W999	W1000
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The measurement results indicate significant CT errors, namely -96.423% (R phase), -91.434% (S phase), and -88.162% (T phase). The corresponding primary currents were 21.8183 A, 20.6454 A, and 23.7353 A, while the secondary currents were 0.07804 A, 0.17685 A, and 0.28098 A, respectively. The CT ratio applied was 50/5. The error calculation is presented in the following equation.

$$\text{Error CT} = \frac{(Kt \times I_s) - I_p}{I_p} \times 100 = \% \quad \dots\dots\dots(1)$$

Dimana Kt adalah Ration CT = 10

$$\bullet \text{ Error CT Phasa R} = \frac{((10 \times 0,07804) - 21,8183)}{21,8183} \times 100 = \% \quad \dots\dots\dots(2)$$

$$\text{Error CT Phasa R} = \frac{(0,7804 - 21,8183)}{21,8183} \times 100 = \% \quad \dots\dots\dots(3)$$

$$\text{Error CT Phasa R} = (-0,96423) \times 100 = \% \quad \dots\dots\dots(4)$$

$$\text{Error CT Phasa R} = -96,423\%$$

$$\blacksquare \text{ Error CT Phasa S} = \frac{((10 \times 0,17685) - 20,6454)}{20,6454} \times 100 = \% \quad \dots\dots\dots(5)$$

$$\text{Error CT Phasa S} = \frac{(1,7685 - 20,6454)}{20,6454} \times 100 = \% \quad \dots\dots\dots(6)$$

$$\text{Error CT Phasa S} = (-0,91894) \times 100 = \% \quad \dots\dots\dots(7)$$

$$\text{Error CT Phasa S} = -91,894\%$$

$$\blacksquare \text{ Error CT Phasa T} = \frac{((10 \times 0,28098) - 23,7353)}{23,7353} \times 100 = \% \quad \dots\dots\dots(8)$$

$$\text{Error CT Phasa T} = \frac{(2,8098 - 23,7353)}{23,7353} \times 100 = \% \quad \dots\dots\dots(9)$$

$$\text{Error CT Phasa T} = (-0,881619) \times 100 = \% \quad \dots\dots\dots(10)$$

$$\text{Error CT Phasa T} = -88,1619\%$$

Accordingly, the average CT error for this customer was -92.0063% . Visual inspection revealed that the PLN-side cubicle ducting was flooded and corroded, and the cubicle CT was burnt and cracked. These conditions are illustrated in Figure 5.



Figure 5. Flooded Cubicle Ducting and Burnt, Physically Cracked CT on the PLN-Side Cubicle

● Corrective Actions for Customer PT Tommy*

1. Replacement of the CT in accordance with the installed CT ratio, as shown in the figure below.

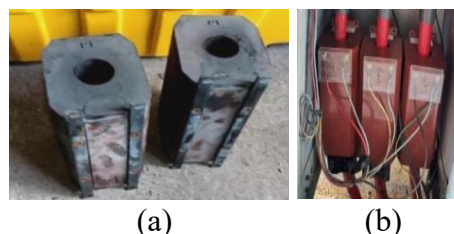


Figure 6. (a) CT condition before replacement, (b) newly installed CT after replacement

2. Rehabilitation of the cubicle room by draining the accumulated water around the cubicle ducting and renovating the cubicle room. The rehabilitation process of the cubicle room is shown in the figure below.



Figure 7. The process of draining the accumulated water around the cubicle ducting

● Results of Monthly kWh Consumption Inspection (DPM Monitoring)

The monthly kWh consumption of PT Tommy* after the corrective actions is shown in Figure 8.

NAMA	TARIF	DAYA	PEM KWH (MON DPM)							STATUS	
			AGT	SEPT	OKT	NOV	DES	SELISIH	AVERAGE		PERSEN
SWP KERNEL ***	G	1730000	582400	234180	403080	417020	373540	69560	396089	-15%	RATA-RATA NORMAL
PT KURNIA ***	G	1110000	202560	209480	196220	NA	196960	26920	176223	5%	RATA-RATA NORMAL
PT INDOHAKMUR ***	G	1110000	115904	175972	280256	287136	172096	5328	147668	14%	NAK
PT TIMAH ***	G	1385000	176020	171520	171360	196320	189140	17260	172246	-16%	RATA-RATA NORMAL
PT. HAFIDAR ***	G	555000	129240	108184	91944	15816	3000	37608	119894	27%	RATA-RATA NORMAL
RSU ***	S3	345000	143732	136028	133004	125020	124828	3016	123747	175%	NAK
PT TIMAH ***	G	1110000	145208	146240	140128	146856	144752	-11312	92197	14%	RATA-RATA NORMAL
PT. DPOH ***	G	1110000	35224	74752	134688	193808	184144	-79920	178658	34%	RATA-RATA NORMAL
PT. WIDA ***	G	555000	178468	200144	193064	70152	94488	7136	125345	10%	RATA-RATA NORMAL
PABRIK ***	G	555000	70968	85848	73168	75744	88776	-10192	53649	104%	NAK
PT BELITUNG ***	G	1110000	66904	69240	73888	132112	125408	-4528	76679	23%	RATA-RATA NORMAL
PT SWIP ***	G	555000	43576	37024	33904	42536	46104	8048	37316	126%	NAK
CV. BELTM ***	G	890000	72552	109400	158152	164096	99872	18336	56447	56%	RATA-RATA NORMAL
POMPA PT ***	G	345000	21700	30748	50272	46944	33928	-780	25633	131%	NAK
PT TOMMY ***	G	865000	11220	81880	8680	175880	228248	-15760	23180	197%	NAK
PT BABEL ***	G	240000	8400	7660	8480	7920	6540	-520	7843	240%	NAK
PT ANTASENA ***	G	345000	7424	27616	30004	69880	89880	1468	210	513%	NAK
PROCESING ***	G	240000	3912	5984	8048	10264	5324	1096	157	174%	NAK
PT KARYA ***	G	1110000	0	0	0	32	1778	0	0	-	RATA-RATA NORMAL

Figure 8. Monthly kWh Consumption (DPM Monitoring) of PT Tommy*

Based on the DPM monitoring results shown above, the customer's monthly kWh consumption increased by up to 197% after corrective actions were implemented on the field-installed equipment.

2. PT Tima* T**

a. Monthly kWh Consumption Inspection (DPM Monitoring)

DPM monitoring shows a decrease in monthly kWh consumption in May 2023 to 28,000 kWh, down from the previous average of 100,000 kWh per month. The data are presented in Figure 9.

NAMA	TARIF	DAYA	PEM KWH (MON DPM)				
			JAN	FEB	MAR	APR	MAY
SWP KERNEL ***	G	1730000	328540	388040	332760	279780	364720
PT KURNIA ***	G	1110000	17820	158820	183180	152580	198180
PT INDOHAKMUR ***	G	1110000	18720	171840	113080	176380	226210
PT TIMAH ***	G	1385000	168880	154180	171480	131280	263780
PT. HAFIDAR ***	G	555000	109624	111088	159154	139672	84120
RSU ***	G	345000	11384	111880	129832	114780	130884
PT. TIMAH ***	G	1110000	208820	179360	155456	158488	212880
PT. DPOH ***	G	555000	118488	92352	151784	101080	211684
PABRIK ***	G	555000	0	10304	80800	81384	78416
PT BELITUNG ***	G	1110000	124984	118884	101576	52788	57564
PT SWIP ***	G	555000	56800	35176	27112	30160	10880
CV. BELTM ***	G	890000	83800	86488	123320	38936	4720
POMPA PT ***	G	345000	32480	22720	26788	14884	27036
PT TOMMY ***	G	865000	0	8640	38820	4596	4200
PT BABEL ***	G	240000	8000	8140	8000	7140	8180
PT ANTASENA ***	G	345000	0	0	0	0	0
PROCESING ***	G	240000	0	0	0	0	0
PT KARYA ***	G	1110000	0	0	0	0	0

Figure 9. DPM Monitoring

b. AMR Reading Inspection via the Amicon Application

The AMR readings obtained via the Amicon application (Figure 10) indicate an undervoltage anomaly, characterized by the loss of voltage in the R phase with a recorded kWh voltage value of zero.

Figure 10. Instant Data Display from AMR Readings in the Amicon Application Showing Zero Voltage on the R Phase

c. On-Site APP Inspection

On 27 June 2023, the inspection results indicated an R-phase voltage of 0 V and a current of 0.77 A, as shown in Figure 11

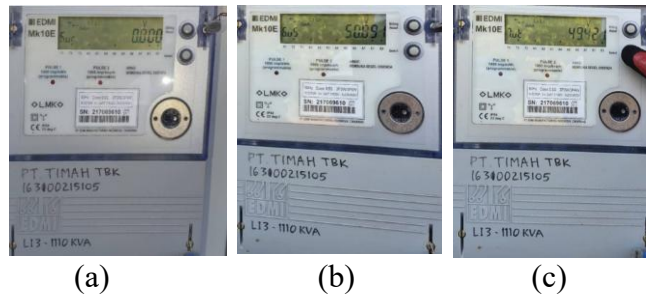


Figure 11. (a) Vr, (b) Vs, (c) Vt

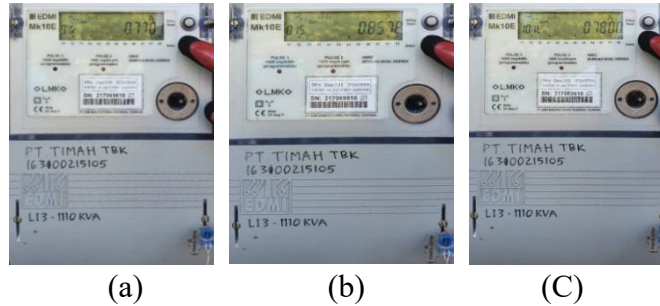


Figure 12. (a) Arus Phasa R, (b) Arus Phasa S, (c) Arus Phasa T

Test Results Using the Calibration Test Instrument Before Corrective Actions

After testing with the kWh calibration test instrument, the measured R-phase voltage was 11.01 V, the S-phase voltage was 49.73 V, and the T-phase voltage was 49.42 V. The kWh measurement results obtained using the calibration test instrument are shown in Figure 13 below.

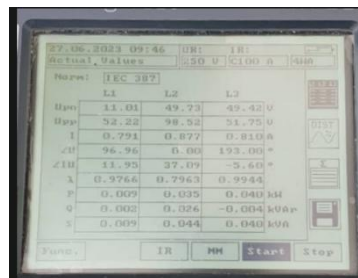


Figure 13. kWh Meter Test Results for PT Timah*

Physical Inspection Results for PT Timah***

The inspection process included examination of the CTs and PTs in the cubicle, wiring configuration, and the physical condition of each component. The inspection process is shown in the figure below.

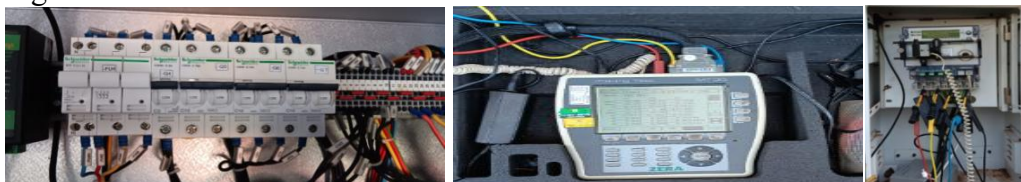


Figure 14. Inspection of Customer PT Timah***

The R-phase voltage loss was caused by the VT output cable becoming detached from the MCB bolt. In the Schneider cubicle, the VT cable supplying the kWh meter passes through a terminal block and an MCB; therefore, when the cable became detached, the voltage at the kWh meter was also lost. The configuration is illustrated in the following single-line diagram.

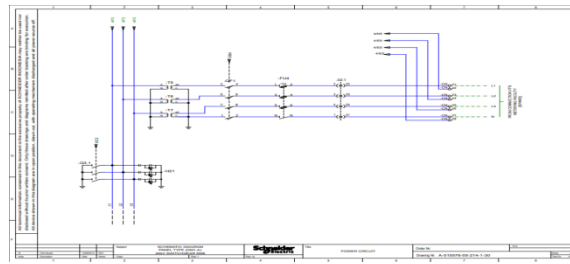


Figure 15. Single Line Diagram Wiring Kubikel Schneider

Corrective Actions for Customer PT Timah***

1. The cable that had become detached from the MCB bolt was reconnected, restoring the voltage supply to the kWh meter to normal conditions. The test results indicate that the R-phase voltage has returned to normal, as shown in **Figure 16**.



Figure 16. Measurement Results After Corrective Actions

Simulation of Measured Power and Meter Error Calculation for PT Timah***

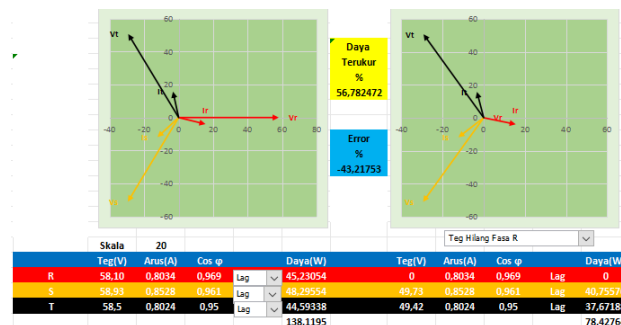


Figure 17. Simulation of kWh Error Calculation After Corrective Actions

Normal Condition: Power Measured at the kWh Meter:

$$Pr = Vr \times Ir \times \cos \phi_r = 58,10 \times 0,803 \times 0,969 = 45,23 \text{ W} \dots\dots\dots (4.16)$$

$$Ps = Vs \times Is \times \cos \phi_s = 58,93 \times 0,853 \times 0,961 = 48,29 \text{ W} \dots\dots\dots (4.17)$$

$$Pt = Vt \times It \times \cos \phi_t = 58,5 \times 0,8024 \times 0,95 = 44,59 \text{ W} \dots\dots\dots (4.18)$$

Jumlah = 138,11W

Phase R Voltage Condition 0 (Zero), Power Measured on the kWh Meter:

$$Pr = Vr \times Ir \times \cos \phi_r = 0 \times 0,8034 \times 0,969 = 0 \text{ W} \dots\dots\dots (4.6)$$

$$Ps = Vs \times Is \times \cos \phi_s = 49,73 \times 0,8528 \times 0,961 = 40,75 \text{ W} \dots\dots\dots (4.7)$$

$$Pt = Vt \times It \times \cos \phi_t = 49,42 \times 0,8024 \times 0,95 = 37,67 \text{ W} \dots\dots\dots (4.8)$$

Jumlah = 78,42 W

Measured Power

$$P = \frac{78,42}{138,11} \times 100\% = 56,78 \text{ \%} \dots\dots\dots (4.19)$$

Error

$$E = \left(\frac{78,42}{138,3} - 1 \right) \times 100 \text{ \%} = -43,21 \text{ \%} \dots\dots\dots (4.20)$$

Comparison of kWh Consumption Before and After Repair

NAMA	TARIF	DAYA	PEM KWH (MON DPM)												STATUS
			MEI	JUN	JUL	AGT	SEPT	OKT	NOV	DES	SELISIH	AVERAGE	PERSEN		
SVP KERNEL ***	G	1730000	364720	509200	578760	582400	234180	403000	417020	373540	69560	396089	-15%	RATA-RATA NORMAL	
PT KURNIA ***	G	1110000	196180	175180	202100	202560	209480	196220	#N/A	196960	28920	178233	-25%	RATA-RATA NORMAL	
PT INDIAMAKMUR ***	G	1110000	129216	166368	171696	115904	175872	200256	287136	172096	5320	147568	34%	NAIK	
PT. TIMAH ***	G	1385000	263760	149480	186740	176020	171520	171360	186320	189140	17280	172246	20%	RATA-RATA NORMAL	
PT. HAFIDAR ***	G	555500	84120	98920	136528	128240	108184	91944	15916	3000	37808	118994	29%	RATA-RATA NORMAL	
RSU ***	S3	345000	130804	132288	135336	143732	138020	133004	125020	124028	3916	123747	100%	NAIK	
PT TIMAH ***	G	1110000	28320	127344	92432	146208	146208	146128	166956	146752	-71312	32107	-44%	RATA-RATA NORMAL	
PT. DIPON ***	G	1110000	212380	170704	90784	38224	74752	134856	192008	184144	-79620	178658	22%	RATA-RATA NORMAL	
PT. WIDIA ***	G	555000	211944	73912	81048	179488	200144	153984	70152	94488	7136	125345	40%	RATA-RATA NORMAL	
PABRIK ***	G	555500	78416	78416	88224	70988	85848	73168	75744	80776	-18182	53648	164%	NAIK	
PT BELITUNG ***	G	1110000	57804	53192	48664	66904	68040	73888	132112	125408	-4528	76679	23%	RATA-RATA NORMAL	
PT SWP ***	G	555500	35880	38824	47672	43576	37024	33904	42536	46104	8848	37318	120%	NAIK	
CV. BELTIM ***	G	690000	4720	12784	32120	72552	109400	158152	184996	98872	19336	56447	-25%	RATA-RATA NORMAL	
POIMPA PT ***	G	345000	27036	27644	26864	21700	30748	50272	48944	33928	-780	25633	131%	NAIK	
PT TOMMY ***	G	885000	42000	41060	25300	11220	81600	8680	175880	228240	-15760	28180	187%	NAIK	
PT BABEL ***	G	240000	8180	7980	7460	8400	7680	8480	7920	8540	-520	7843	240%	NAIK	
PT ANTASENA ***	G	345000	0	0	1488	7424	27816	30004	69880	69880	1488	210	512%	NAIK	
PROCESHINO ***	G	240000	0	0	1096	3912	5984	8048	10264	5324	1096	157	174%	NAIK	
PT KARYA ***	G	1110000	0	0	0	0	0	0	32	1776	0	0	-	RATA-RATA NORMAL	

Figure 18. Monthly kWh Consumption Monitoring (DPM Monitoring) After Repair

From the figure above, a significant change in the monthly kWh consumption of this customer can be observed. In month 5, PT Timah***'s kWh consumption was only 28,000 kWh after the repair. In the following months, the kWh consumption increased considerably, remaining above 100,000 kWh per month. The test results are presented in Table 1.

Table 1. The Test Results

No	Customer Name	Deviation Before (%)	Deviation After (%)	Technical Notes
1	PT Tommy U**	2.5	0.3	CT malfunction occurred; current transformer replaced.
2	PT Timah ***	3.2	0.4	Broken cable on the VT output side; cable reconnected..
3	PT Hafidar Nusantara	1.8	1.5	Values within tolerance limits; no repair performed.

The test results indicate that the deviation values before repair were relatively high ($>2\%$), suggesting the presence of energy measurement errors. After the repair, all customers showed a significant reduction in deviation to below 2%, indicating that the APP (energy metering device) had returned to accurate operation. These findings suggest that common errors in the APP are caused by:

- CT/PT transformer damage, resulting in disproportionate current and voltage readings.
- Disconnected cables on the VT output side, causing active energy to go unrecorded.
- Phase load imbalance, which affects power and power factor ($\cos \phi$) values.

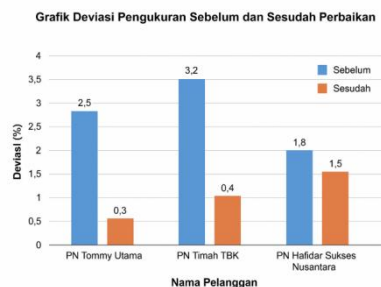


Figure 19. Measurement Deviation Graph Before and After Repair

Classification Analysis Using Machine Learning

To support the technical analysis, this study applies the Random Forest Classifier algorithm in the classification of APP (Energy Metering and Limiting Device) conditions. The purpose of

applying this model is to identify measurement deviation conditions based on digital data from PLN's Daily Performance Monitoring (DPM) system. The results of the Machine Learning model testing are shown in Figure 20 below.

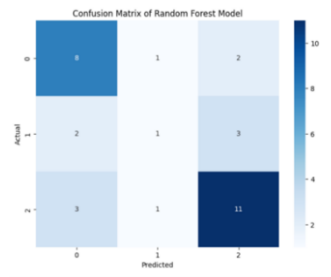


Figure 20. Confusion Matrix of APP Condition Classification Results (Random Forest Classifier)

The measurement data were used to train the Random Forest Classifier model. This model classifies APP conditions into three categories: Normal, Minor Deviation, and Major Deviation. The training results yielded an accuracy of 83.8%, a precision of 0.91, a recall of 0.89, and an RMSE of 0.42. These results demonstrate the potential of machine learning to assist PLN in implementing a DPM-based early warning system.

Conclusion

Based on the research results, it can be concluded that APP testing using WS2330 and PLN's DPM data provides consistent outcomes. After technical repairs were performed, all customers showed a significant reduction in deviation, bringing the values within the SPLN 34-2:2012 tolerance limits. The application of the Random Forest Classifier was able to automatically classify APP conditions with an accuracy of up to 83.8%. This approach can be further developed into a Hybrid Monitoring System, an integrated monitoring system combining field measurements and DPM digital data, to detect deviations early and support predictive maintenance of APP at PLN.

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