Development of FLISR Algorithm with Additional Consideration of Reliability Index, Losses, and Load Forecasting, Case Study in Central Java Distribution, Indonesia

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***Abstract*— This paper proposes an enhancement to the existing Fault Location, Isolation, and Service Restoration (FLISR) system implemented in the Advanced Distribution Management System (ADMS) of *PLN Central Java & Yogyakarta*. The current system focuses on equipment capacity and switching operations. However, this study introduces additional variables such as the reliability index, disturbance history, technical losses, and load forecasting to improve system efficiency and reliability. A case study conducted on the KDS15 feeder demonstrates how these new variables optimize network reconfiguration, significantly reducing potential losses and disturbances. The FLISR algorithm's decision-making process was enhanced by using the Simple Additive Weighting (SAW) method to prioritize network sections for restoration, yielding more reliable results compared to the original method. Simulation results show a reduction in technical losses, improved prioritization of network recovery, and reduced recurrence of disturbances. Most required ata is accessible through Supervisory Control and Data Acquisition (SCADA), except for health index data, which remains unintegrated. The novelty of this research lies in integrating additional variables into the FLISR recovery process, demonstrating its potential to improve distribution network reliability and efficiency.**

Keywords - FLISR, ADMS, reliability index, losses, SCADA.

I. Introduction

The development of electric power distribution utilities is rapidly advancing, starting with the implementation of SCADA, which assists power operators in controlling and monitoring equipment in real-time [1]. Currently, it has evolved beyond mere monitoring and control, encompassing analysis and optimization of the distribution network under both normal operations and during faults. This development is part of the ADMS [2] .

ADMS comprises five stages: Remote Control and Monitoring SCADA, Outage Management Prediction Analysis, Network Visualization Tools, Power Flow Analysis Study Model Tools, and Network Optimization [3].

In the *PLN Central Java & DI Yogyakarta* area, one of the ADMS features that has been implemented is FLISR, which falls under the category of Outage Management Prediction Analysis, FLISR is also regarded as the most crucial function for reducing outage duration and enhancing service reliability [4], This helps to enhance overall reliability, aligning with the needs of both customers and the utility. [5]. The distribution network system in central java still uses Medium Voltage Overhead Line with a radial open loop system, connected by switching equipment such as Load Break Switches (LBS) between feeders. The radial system with several branches connected to multiple feeders presents a unique challenge for FLISR implementation, particularly in the fault locator system expected to indicate the distance to the fault location. Additionally, other challenges include uneven load factors at certain hours and the health of sections for the recovery process to prevent repeated outages for customers. These challenges require further development that takes into account additional variables to improve the reliability of the distribution network. The benefits of FLISR are increased reliability, reduced outage duration, and operational flexibility [6].

Currently, FLISR only considers the condition and capability of the equipment and the number of switching in operation. This study proposes adding variables such as reliability index (historical disturbances and inspection results), losses, and load forecasting to enhance the efficiency and reliability of the electric power distribution system in the implementation of FLISR at *PLN Central Java & DI Yogyakarta*, using the KDS15 feeder as a case study.

II. FLISR Overview

This research develops a FLISR algorithm that currently only considers the number of switching operations and the feeder's ability to handle overflow loads. We then add several new variables, namely reliability index, disturbance history, cumulative losses and load forecasting for the distribution network section. The current workflow of FLISR can be seen in the figure 1 below.

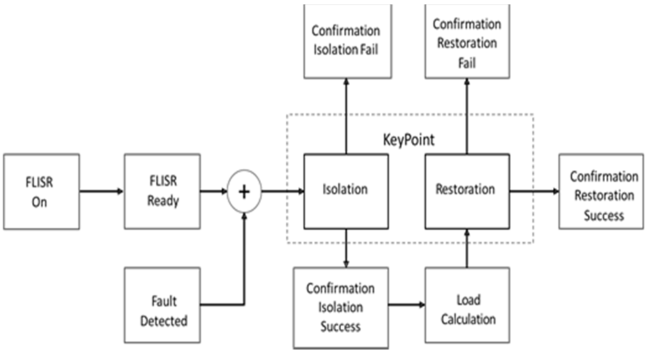

Fig. 1 FLISR workflow diagram

The descriptions of the added variables are as follows:

A. Health Index

Health Index is a quantitative method for assessing the current condition of assets or electrical equipment and predicting their future condition based on historical data and the level of maintenance performed[7]. The data used in the Health Index are the results of inspections conducted by personnel on the distribution network. The equipment inspected includes poles, networks (conductors and jumpers), ROW, insulators, installed protection devices, installed switching equipment, and distribution transformers. Inspection tools such as binoculars, PD cameras, and thermo vision are used. These inspections also capture the location of the installed equipment as a parameter for potential incidents, allowing all potential disturbances to be depicted from the inspection results. These inspection results are used to illustrate the potential for disturbances, which can reduce the reliability of the network. The purpose of using this parameter is to ensure that, after the recovery process, the disturbed segment does not experience recurring outages. The more inspection findings there are, the lower the value of that segment, thus lowering its priority ranking.

B. Disturbance History

The latest disturbance data is obtained from the protection history of each section recorded in the SCADA system. This data illustrates the reliability condition of the section over the past year. The purpose of using this variable is almost the same as the health index variable, which is to ensure that after the recovery process in a normalized section, there are no recurring outages in that section. The more disturbances that have occurred, the lower the value of that section, thus reducing its priority ranking.

C. Technical losses

Technical losses in the distribution system are caused by the physical and operational properties of the electrical network components, one of which is due to cable resistance [8]. These technical losses generally include losses caused by the flow of electric current through conductive materials with specific resistance [9]. The basic formula for calculating losses due to cable resistance is I^2R. The network configuration pattern will result in losses, so to minimize technical losses, we must calculate each network configuration we choose. Smaller losses due to reconfiguration will make a better score in the configuration selection for FLISR.

D. Load forecasting

Load forecasting is the process of estimating future electricity demand based on historical data and current trends [10]. This process is crucial when reconfiguring the distribution network to prevent overloads that could cause power outages. If the load forecasting calculations indicate an overload at certain hours, it is advisable not to proceed with the FLISR recovery implementation. Reliable forecasting will be a critical component in many of these systems to anticipate and reduce the risk of failures [11].

All the new variables mentioned above are added to the FLISR working algorithm to serve as a basis for decision-making in restoring or recovering sections that can be normalized, rather than those that are disturbed. This type of analysis of distribution network processes is essential for developing algorithms that operate the digital infrastructure of the SCADA system [12]. By applying the SAW method, we can determine the optimal decision. The evaluation scores for each variable are obtained by multiplying the scale values of the alternative variables by the relative importance weights provided by the decision-makers. Then, the results of these multiplications are summed up for all criteria. The steps for implementing the SAW method, based on the theory and implementation of decision support systems, include calculating the normalization values of the existing variables and then calculating the total score [13].

III. DEVELOPMENT OF FLISR ALGORITHM

A. Data Collection

In this research, a case study will be conducted on feeder KDS15, which is one of the feeders in *PLN Central Java & DI Yogyakarta*, specifically in the *UP3 Kudus*. The single line diagram of feeder KDS15 can be seen in Figure 2 below.

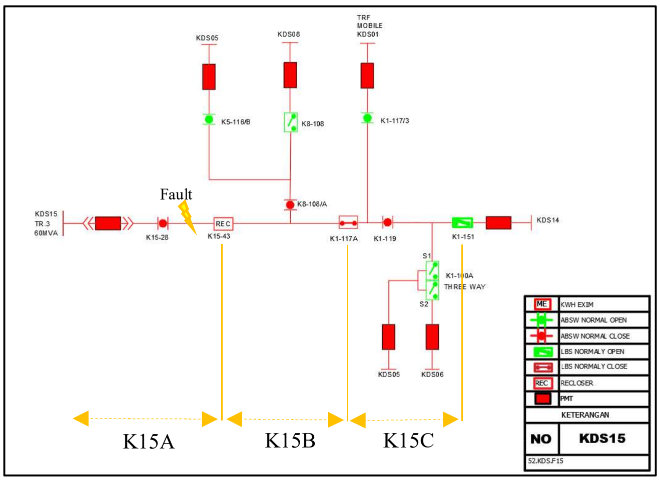

Fig. 2 Single Line diagram KDS15

In addition to the SLD data for KDS15, average hourly load data for April 2024 was also obtained for feeder KDS15 and other feeders connected to KDS15. This data will serve as a reference and simulation for FLISR operation, considering recovery capability, post-reconfiguration network losses, and load forecast after network reconfiguration. The load data can be seen in Figure 3 below:

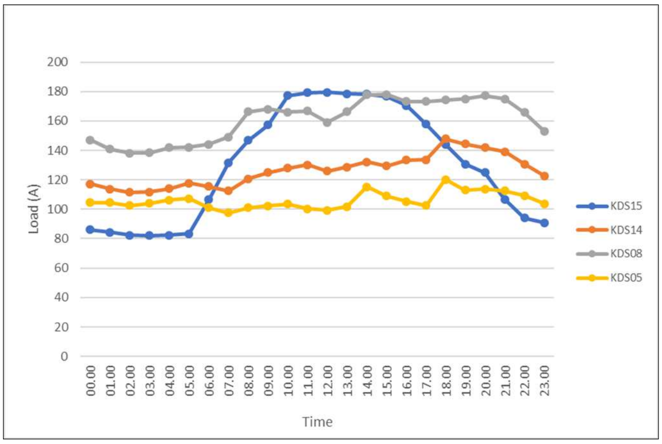

Fig. 3 Load Curve

The graph above (Figur 3) shows the average hourly load curve April 2024 for four different feeders (KDS15, KDS14, KDS08, KDS05) connected to KDS15 over a 24-hour period.

Besides the load data, there is also section data for the four feeders along with the network lengths. From this data, it is known that all four feeders use A3C conductors with a cross-sectional area of 240 mm². This data can be seen in the table below:

Table 1. Technical Feeder Data

Feeder	Section Name	Code Of Section	Conductor Length (km)	Max Load	Average Load (Ampere)	Health Index Section	Fault History Last Year
KDS-15	KDS-15 - REC K15-43	K15 A	1,7	400	180	0	5
	REC K15-43 - LBS K1-117A	K15 B	9,84		178	0	10
	LBS K1-117-A - K1-151	K15 C	3,79		74	4	3
KDS-08	KDS-08 - REC K8-48	K08 A	3,5	400	159	0	2
	REC K8-48 - LBS K8-108	K08 B	5,3		155	0	17
	LBS K5-133M - LBS K1-78	K08 C	3		61	0	1
KDS-14	KDS-14 - REC K14-70	K14 A	3	400	126	0	6
	REC K14-70 - LBS K1-203	K14 B	3,75		120	0	12
	LBS K1-203 - LBS K1-151	K14 C	3,9		66	0	9
KDS-05	KDS-05 - REC K5-60	K05 A	4,18	400	100	0	4
	REC K5-60 - LBS K5-135	K05 B	5,49		86	0	7
	LBS K5-135 - LBS K5-202	K05 C	9,82		66	0	18
	LBS K5-202 - LBS K5-246	K05 D	5,96		26	1	3

All the above data are used as a basis for decision-making in the recovery or restoration process when FLISR works to normalize sections without faults. For example, in KDS15, a simulation was conducted where a fault occurred in the 20 kV network section K15A, causing the outgoing protection of KDS15 to operate and resulting in an outage for all KDS15 customers. Since the fault is in section K15A, customers in sections K15B and K15C can be automatically normalized by FLISR.

B. Equations

The process of determining the feeder that receives the load transfer from the faulted feeder, mathematical optimization calculations are performed using the SAW theory. The steps in data processing include normalizing the data and then calculating the scores for each variable. The mathematical formulation was designed so that other optimization techniques can be applied to solve this multi-objective problem [14]. The following are the equations used for scoring variables and calculating variable values:

1) Technical losses in distribution network

$$P\ loss = I^2 R \tag{1}$$

Resistance can be calculated using the formula:

$$R = \rho . \frac{L}{A} \tag{2}$$

$P\ loss = Power\ losses\ in\ watts\ (W)$
$I = Electric\ current\ flowing\ through\ the\ conductor\ (A)$
$R = Resistance\ of\ the\ conductor\ in\ ohms\ (\Omega)$
$\rho = Resistivity\ of\ the\ conductor\ material\ (\Omega \cdot m)$
$A = Cross - sectional\ area\ of\ the\ conductor\ (m^2)$

2) Load Forecast Score

The calculation for the load forecast score is done by examining the highest load values transferred (K15B and K15C) that are summed with the feeder that will receive the load from K15B and K15C. If an overload occurs, the score will be 0; if there is no overload at the highest load, the score will be 1.

3) Health Index Score

The score value for the health index section is determined by the following criteria: If there are findings in the section inspection results, the score will be less than 1 (depending on the number of findings), and if there are no findings in the section inspection results, the score will be 1.

4) Data Normalization:

For criteria where lower values are better, use:

$$R_{ij} = \frac{X_{min}}{X_{ij}} \tag{3}$$

For criteria where more is better, use:

$$R_{ij} = \frac{X_{ij}}{X_{max}} \tag{4}$$

Where:
$R_{ij} = normalized\ value\ for\ the\ i-th\ and\ j-th\ criteria$
$X_{min} = minimum\ value\ from\ data\ for\ the\ i-th\ criteria$
$X_{max} = maximum\ value\ from\ data\ for\ the\ i-th\ criteria$
$X_{ij} = data\ value\ for\ the\ i-th\ criteria$

5) Final Score:

Since all variables have the same weight, the final score is calculated by summing all the normalized data scores.

$$S_j = \sum_{i=n}^{n} R_{ij} \tag{5}$$

Where:
$S_j = final\ score\ for\ the\ j-th\ alternative$
$R_{ij} = normalized\ value\ for\ the\ i-th\ and\ j-th\ criteria$
$n = number\ of\ criteria$

IV. RESULT & DISCUSSION

By using the data from Table 1, the single line diagram of KDS15 and the equations (1), we simulate the KDS15 distribution network during a disturbance in section K15A. In this situation, FLISR has several options to recover sections K15B and K15C, which are not disturbed. The calculation results for each variable is presented in the table below:

Table 2. Calculation Data

Option Plan	Configuration Plan	Total Load (Ampere)	Operational of Switching (times)	losses (kW)	Fault History in Last Year (times)	Health Index	Load Forcast (Over Load)
Option 1	KDS08 + K15 B + K15 C	337	2	339	10	GOOD	NO
Option 2	KDS14 + K15 B + K15 C	304	2	206	12	GOOD	NO
Option 3	KDS05 + K15 B + K15 C	278	2	306	28	BAD	NO
Option 4	KDS08 + K15 B & KDS14 + K15 C	263 & 200	4	244	22	GOOD	NO
Option 5	KDS08 + K15 B & KDS05 + K15 C	263 & 174	4	280	38	BAD	NO

The data in Table 2 explains the simulation results of the possible options for recovering K15B and K15C. From the table, the values of each variable that will serve as the basis for calculating the scores can be seen. Using the data from Table 2, along with Equation 4 and Equation 5, we can obtain the scoring results to determine the priority of network reconfiguration. With the old method that only uses two variables, the priority can be seen in the following table:

Table 3. Simulation Score with 2 variable

Option Plan	Configuration Plan	Total Load score	Operational of Switching score	Total Score	Priority Option
Option 1	KDS08 + K15 B + K15 C	1	1,0	1,5	3
Option 2	KDS14 + K15 B + K15 C	1	1,0	1,6	2
Option 3	KDS05 + K15 B + K15 C	1	1,0	1,7	1
Option 4	KDS08 + K15 B & KDS14 + K15 C	0,76	0,5	1,3	5
Option 5	KDS08 + K15 B & KDS05 + K15 C	0,82	0,5	1,3	4

Table Data 3 explains the scoring for each variable from the simulation results when a disturbance occurs in section K15A of KDS15. By examining the accumulated scores, the highest score, which represents the best option, is found in option 3. Therefore, according to the old algorithm, FLISR will work to normalize K15B and K15C to the KDS05 feeder. This score only considers two variables, there are switching frequency and total load after reconfiguration variable. The weakness of using two variables that produce this priority is the high potential for losses (ranked second worst) and also the high potential for disturbances (ranked second in disturbance potential), thus failing to achieve a reliable and efficient network.

Table 4. Simulation Score with 6 variable

Option Plan	Configuration Plan	Total Load score	Switching score	losses score	Fault History score	HI score	Load Forcast (Normal =1, OL=0)	Total Score	Priority Option
Option 1	KDS08 + K15 B + K15 C	1	1,0	0,6	1,0	1,0	1	5,14	2
Option 2	KDS14 + K15 B + K15 C	1	1,0	1,0	0,8	1,0	1	5,44	1
Option 3	KDS05 + K15 B + K15 C	1	1,0	0,7	0,4	0,5	1	4,18	4
Option 4	KDS08 + K15 B & KDS14 + K15 C	0,76	0,5	0,8	0,5	1,0	1	4,56	3
Option 5	KDS08 + K15 B & KDS05 + K15 C	0,82	0,5	0,7	0,3	0,5	1	3,81	5

The data in Table 4 explains the scoring for each variable from the simulation when KDS15 experiences a disturbance in section K15A. By examining the accumulated scores, sections K15B and K15C will be recovered to the feeder with the highest score, which is option 2 (feeder KDS14). According to Table 2, option 2 has the smallest losses and the second-best disturbance potential.

Referring to the data in Tables 3 and 4, it can be seen that the addition of variables in the FLISR recovery process can significantly improve the efficiency and reliability of the distribution network. Faster and more accurate power recovery for customers will enhance utility reliability, as indicated by the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI) [15]. Most of the required data is already available in the SCADA system, including load data, disruption history, switching frequency, and technical losses (utilizing the load flow feature on the SCADA master). However, the health index data (inspection results), which resides in another application, has not yet been integrated into the SCADA system. Therefore, it is recommended to integrate health index data into the SCADA system in the future. Additionally, the FLISR output must also be able to change active settings on protection devices to ensure that protection coordination functions well without anomalies.

Table 5. Comparison of decision results

FLISR Algorithm	Configuration Plan	Total Load (Ampere)	Operational of Switching (times)	losses (kW)	Fault History in Last Year (times)	Health Index	Load Forcast (Over Load)
Old	KDS05 + K15 B + K15 C	278	2	306	28	BAD	NO
New	KDS14 + K15 B + K15 C	304	2	206	12	GOOD	NO

From the existing data, we can conclude that a smaller total load is preferable, a lower shrinkage value is better, fewer disturbance occurrences indicate higher reliability, fewer findings in the health index signify better condition, and the absence of overload is optimal.

With the development of the algorithm explained above, there are changes to the FLISR workflow flowchart. The new flowchart is illustrated in the figure below:

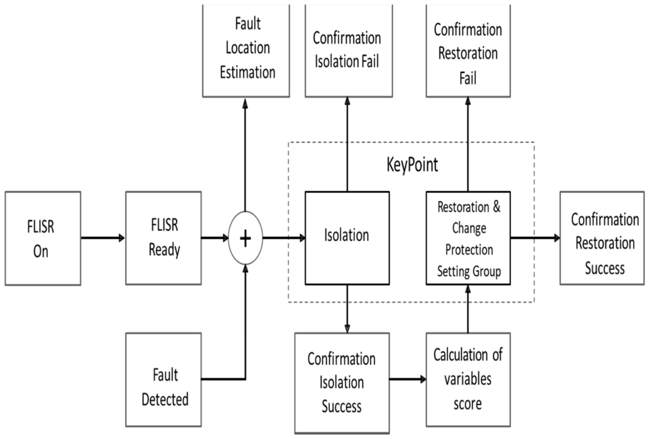

Fig. 4 New FLISR workflow diagram

V. CONCLUSION

This research demonstrates that the development of the FLISR algorithm with the addition of new variables such as reliability index, disturbance history, technical losses, and load forecasting can improve the efficiency and reliability of the electric power distribution system. The simulation on the KDS15 feeder in *PLN Central Java & DIY* shows that the new method using six variables provides more optimal results compared to the old method that only considers two variables. The updated FLISR algorithm implementation can reduce technical losses, decrease potential repetition of disturbances, and improve the priority of recovering non-faulty network segments. Most of the required data for this algorithm is already available in the SCADA system, including load data, disturbance history, switching frequency, and technical losses. However, health index data from inspection results still need to be integrated into the SCADA system to fully support the implementation of the updated FLISR algorithm.

The novelty of the paper lies in its enhancement of the existing FLISR (Fault Location, Isolation, and Service Restoration) algorithm by integrating additional variables such as the reliability index, disturbance history, technical losses, and load forecasting. These new variables significantly improve the decision-making process for network reconfiguration, making the recovery process more reliable and efficient. Unlike previous works that primarily focus on equipment capacity and switching operations, this research uses a multi-variable approach, applying the Simple Additive Weighting (SAW) method to better prioritize sections of the network for restoration. This approach not only reduces technical losses and the recurrence of disturbances but also optimizes the reliability of the distribution network, offering a more holistic solution than methods used in other studies, which often consider fewer parameters

As the next step, a simulation of the KDS15 FLISR operation in the SCADA system at *PLN UP3 Kudus* will be conducted. It is recommended to integrate health index data into the SCADA system and ensure that the FLISR output can adjust active settings on protection devices to maintain proper protection coordination without anomalies. This will enable a more effective and efficient implementation of FLISR in the *PLN Central Java & DIY* area.

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