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Selecting an Appropriate Scenario for Implementing RCM and RCA to Reduce System Average Interruption Duration Index with Systems Dynamics Approach in Power Distribution Companies

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ABSTRACT

The mission of power companies is to provide standard and reliable electricity to their customers, and one of the threats of not fulfilling this mission is breakdowns and accidents in the electricity network equipment. The System Average Interruption Duration Index (SAIDI) is a critical indicator in the power distribution industry to determine network reliability; Reliability Centered Maintenance (RCM) and root cause analysis (RCA) of failures and applying the results of these two in two dimensions of network maintenance and design, are two effective measures in reducing SAIDI. This paper presents a model for the system and structure that creates SAIDI behavior, which can be simulated to achieve appropriate policies to determine the level of use of RCM and RCA and, thus, the optimal value to reduce the index value. The System simulation method has been used to simulate system behavior. After designing and simulating the cyclic causal model, various scenarios for determining RCM and RCA policies are proposed and reviewed, and the results are presented. The criterion for selecting the appropriate scenario in this article is to reduce the SAIDI index's value further. Based on the research findings, the policies selected have a suitable reducing effect on SAIDI. The model's validity was evaluated through behavior replication testing, extreme condition assessment, and sensitivity analysis. Since the organization's vision in 2026 is to reduce SAIDI to 14 minutes per year, the impact of RCM and RCA policies in different scenarios on the model variables was evaluated. The results showed that if the existing policies are not changed, the process of SAIDI changes will increase. Changing the system approach from non-implementation to implementing RCM and RCA under optimal conditions will decrease SAIDI from 26.73 minutes at the beginning of 2020 to 41.34 minutes by the end of 2026.

Keywords

System dynamics, System average interruption Duration index, Reliability centered maintenance, Root cause analysis, Power distribution companies.

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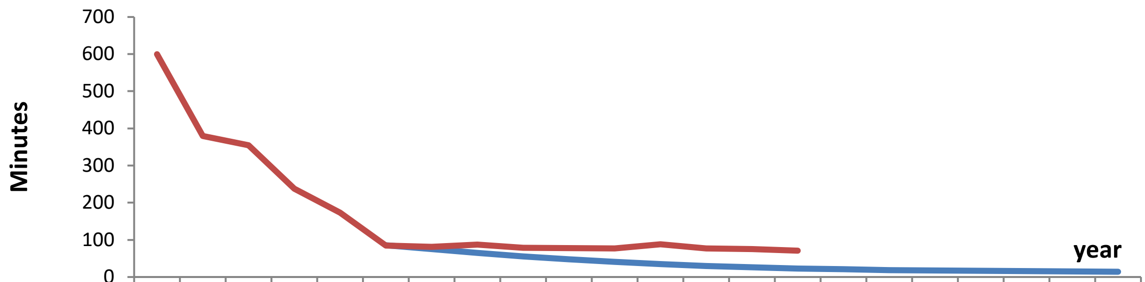
1. Introduction

One of the problems in planning in the management of macro organizations is the failure to achieve the vision and goals of the organization following what has been planned. This issue can be due to the system's resistance to change and the feedback and nonlinear relationships of factors affecting the achievement of goals. Considering the mission of power distribution companies to provide electricity to their subscribers in a stable, reliable, and standard way, the strategic importance of the index "Average shutdown time per subscriber per year"(System Average Interruption Duration Index (SAIDI)) (IEEE, 2012, Jasim Mohammad Al Shaheen, 2017, Tavanir, 2018) From the perspective of these companies and the electricity industry in general, and recognizing the factors affecting the changes in this index has a special place for the development of effective reform programs; Obviously, this indicator indicates the reliability of the power supply network, which also affects another strategic indicator called "Energy Not Supplied"(ENS). Given this mission, the importance of the SAIDI index is evident, and indeed, this philosophy of existence applies to all power distribution companies. Therefore, this index can be considered a "universal" issue for the electricity industry. In this research, Mashhad Electric Energy Distribution Co. (MEEDC), which provides services in Iran, was selected as a case study. This company has reduced SAIDI to 14 minutes in 2026 AD (1405 Hijri-Shamsi). Therefore, it is necessary to study the factors affecting achieving the desired goal and monitor each policy's effectiveness. These factors can be divided into two subsets: "technical" and "non-technical" factors (Anbiaei, 2004). Technical factors and non-technical factors are two categories of factors that affect the behavior of the power grid. Technical factors are related to the physical structure of the power grid and can influence the shutdown rate. Non-technical factors, on the other hand, are not directly related to the physical structure and topology of the network.

According to the company's strategic plan, a trend in 2011-2026 AD to reduce the SAIDI index from 86 to 14 minutes per year was set, and this decreasing trend was estimated annually. In this regard, the company set up operational plans and controlled them through "historical trend control" tables to implement and monitor these plans properly. However, despite all the seriousness and efforts made, this index did not go according to the initial regulatory plan for nine years until 2020, and according to the plan, it should be reduced from 86 to nearly 20 minutes per year. This amount has reached 72 minutes per year (Figure). In this study, SAIDI is the critical variable that needs to be analyzed. However, to understand the behavior of this variable, other concepts should also be considered. These concepts include planned and unplanned blackout rates and delivered energy to subscribers yearly. The reference behavior of the key SAIDI variable from 2005 to 2019 shows a downward and Goal Seeking trend. This trend has had asymmetric fluctuations from 2010 to 2019 (Figure).



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Forecast						86	75	65	56	48	41	35	30	26	23	21	19	18	17	16	15	14
Performance	600	380	355	238	173	85	81	87	79	78	77	88	77	75	71							

Figure 1. Comparison of SAIDI forecasting trend and its realized value (reference behavior)

Figure 1 is prepared based on the forecasted trend in the strategic plan and historical trend data that are available in the MEEDC Dispatching Department. This behavior shows that the purpose of the system is not in line with the purpose of policymakers for the system. The policies set cannot overcome the system's resistance, and there is a need to review existing policies and design new policies. Therefore, this study presents the effect of these policies on the behavior of SAIDI by modeling, simulating, and systematically analyzing the impact of RCM and RCA implementation policies in network design on SAIDI with a systems dynamics approach.

According to the above, the primary purpose of this study is to identify the factors affecting system dynamics affecting the amount of SAIDI in MEEDC as an example to study and model the interaction of these factors with each other and also on the results of the studied system and check the future results of the system, based on applying the selected policies in simulating the model and finally selecting the optimal conditions for implementing the selected policy to change the behavior of the SAIDI index in the desired direction, to achieve the company's goal in 2026. There is little research explicitly examining Energy Not Supplied in systems dynamics. Thurlby (2013) presents an article entitled "Managing the asset time bomb: A system dynamics approach" that examines an asset time bomb through the role of system dynamics in creating modeling capabilities.

By providing a SAIDI chart for 20 years, the researcher shows that if the current asset management policy does not change, there will be a real threat of an asset time bomb, and its impact is imminent. On the other hand, the policy change can eliminate the threat and, in addition, reduce the number of interruptions. Quentara and Suryani (2017) separate the integrated electrical operating system into five subsystems in the system dynamics development model for the operation strategy in the power generation system through the integrated transmission and distribution system. The researchers' main goal is to plan the appropriate operation strategy for the power generation system required on the Indonesian island of Madura so that they can consider the decision to invest in this sector. In their paper, Ghasemianfard and Moosavirad (2017), using the theory of system dynamics, have identified and prioritized the factors affecting the reduction of blackouts and show that implementing improvement policies reduces ENS. Among the policies that these researchers have studied are the practical training of staff and justification of instructions, power outages during off-peak hours and seasons and in the shortest range, standardization of the network, and non-frequent outages in a particular area.

2. Literature review and innovation

With a more general look at the history of studies, these studies have addressed various aspects in recognizing the factors affecting changes in the SAIDI index. However, these efforts are more with a specialized approach and without systemic thinking to examine the effects of a particular factor, and different factors and their effect on each other and SAIDI have yet to be studied simultaneously. Examples of these specialized studies are listed in Table . Of course, the research that Ghasemianfard and Moosavirad (2017) have done concerning the analysis of factors affecting ENS from the system dynamics perspective can be mentioned as an example of research. Nevertheless, Meadows et al. (1982) say that A central principle of system dynamics is to examine issues from multiple perspectives, to expand the boundaries of our mental models to consider the long-term consequences and "side effects" of our actions, including their environmental, cultural, and moral implications (Sterman, 2000); This critique can be attributed to the mentioned study which has paid attention only to the technical aspects of the subject of ENS and has neglected the non-technical aspect; That is, they have studied the effect of technical and non-technical factors without distinguishing between them, in a model that models the system only from a technical point of view. Now, according to the above, in this study, an attempt has been made to pay attention to the dynamics of factors affecting power outages in technical and non-technical dimensions to separate and model these factors in two separate subsystems and create a holistic and systematic view on this issue, to be able, to simulate the actual effect of technical factors on system behavior. In their research, Ghasemianfard and Moosavirad (2017) investigated the analysis of ENS system dynamics in the North Kerman Electricity Distribution Company. In that study, the separation of the effects of non-technical and technical factors was neglected, and technical factors were studied only from the dimension of incidents in the electricity distribution network. Therefore, in this article, with the system thinking approach and using the "systems dynamics" technique, by separating the "technical and non-technical" factors from each other; an attempt has been made to determine their effects on interaction with each other simultaneously in the SAIDI index behavior; and By modeling the existing structure and simulating its behavior, different policies be tested in simulating system behavior; In other words, based on the past behavior of the system, by modeling the system, its behavior in relation to the future effects of selected policies is simulated and then by changing the controllable factors of these selected policies, different scenarios are designed; and these new policies-scenarios, with the same system model that has been discovered, are in the simulation process and the results of future simulation of the selected policies-scenarios are compared, and finally, among these policies-scenarios, the best one is the one whose effects In the future, it shows better results in achieving the goals of the organization, has been selected and introduced as a desirable policy.

Table 1. Examples of research background

Researcher (s)	Model type	Method / approach	Research goal	Type of factors examined
Mohammadi and Rajabi Mashhadi (2019)	Analytical	Game theory/ modeling	a game theoretic approach is designed to model possible strategic behavior of customers in distribution system reliability provision	technical & non-technical
Nourizadeh and Niasati (2020)	Analytical	Optimization	Locating distribution substations to reduce losses and ENS	technical & non-technical
Alimohammadi and Behnamian (2021)	Analytical	Optimization	Preventive maintenance planning of the electricity distribution network to reduce ENS	technical
Gord et al., (2020)	Analytical	transient analysis	Provide fault locating method for distributed networks with distributed generation to reduce the amount of ENS	technical
Tatiétsé et al., (2002)	Analytical	statistical techniques density estimation	proposes an approach to network reliability through modelling the interruptions on medium voltage lines.	technical
Mercado and Sanchez (2021)	Analytical	Mixed Integer Nonlinear Programming (MINLP)/ Optimization	presents a methodology for optimization of reclosers placement in distribution networks	technical

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3. Research methodology

The approach in this study is naturalistic, and qualitative and quantitative methods are the basis of this research. The purpose of this research is applied, which has been in line with the development of knowledge of systems dynamics in electrical energy distribution. It is a descriptive study, and a case study is systemic dynamics affecting the rate of SAIDI in MEEDC.

Due to the limited number of qualified experts in the entire field of operation and issues related to subscriber shutdown in MEEDC, the sample is selected from the community of experts in the field of network operation and maintenance, which, in selecting selected policies for modeling, among the current policies of the organization that affects SAIDI, as well as to discover the factors affecting SAIDI changes and its relationships, this Agents cooperated by participating in expert meetings. The TOPSIS method was used to select the selected policies for modeling, by which, among the policies the organization implements or intends to implement shortly, select two policies or implement the results of RCM and RCA. Then, considering that the RCA committee was held in MEEDC to identify the primary factors effective in reducing SAIDI, the documents of this committee were studied, and based on the results, the relationships between these factors were discovered. In order to formulate the Stocks and Flows Diagram, interview sessions were organized with relevant experts; finally, the Vensim DSS 6.4E software Optimize tool was used to identify and select the optimal policy. Stocks and Flows Diagram parameters such as zero moment values, relationship coefficients between variables, exogenous and other required values, from records of accident registration databases and Geographic Information System (GIS), available in the Deputy of Operation and Maintenance, and interviews with relevant experts, have been collected. The time horizon of the simulation is 21 years, from the beginning of 2005 to the end of 2026, and the simulation period is one year. The available data collected, which can be used to estimate other values, are from 2015 to 2019.

4. Modeling system dynamics

The method used in this research to model the problem is the Sterman (2000) modeling process.

4.1. Problem articulation and boundary selection

The steps of this stage are explained in four sections: Theme selection, introducing critical variables, determination of time horizon, and dynamic problem definition (reference modes). Based on this model, the organization's issues and challenges, which are the system-goal-seeking behavior and resistance to SAIDI reduction, have been explained. Also, according to Figure , the reference behavior of this key variable in the time horizon of 2005 to 2026 was shown from two dimensions: behavior (performance) and desirable behavior (forecast). At this stage, to obtain information about the boundary, the level of integration, and the main endogenous and exogenous variables of the system (Sterman, 2000), a subsystem diagram is designed (Figure 2). This diagram shows how the SAIDI subsystem is affected by other subsystems within the model. This diagram shows that the SAIDI subsystem is affected by three variables: ENS, SAIDI Vision, and DE.

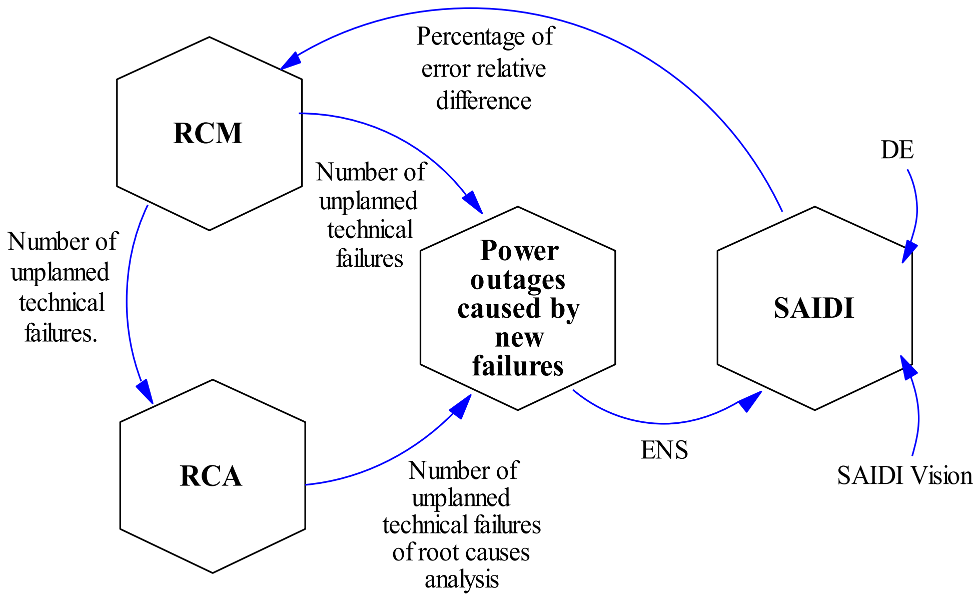

Figure 2. Diagram of SAIDI creator subsystem

4.2. Causal loop diagrams and dynamic hypothesis

Due to raising the issue and demonstrating the system's dynamics, CLDs of the initial dynamics hypothesis were presented to a committee of experts, and the proposed hypothesis and model were reviewed using the SODA II (Azar et al., 2013) method. The steps of this method were carried out so that an initial group mental map was prepared by holding a brainstorming session and presenting the experts' opinions. After that, in the second session, this mental map was exposed to the group of experts, new relationships and concepts were discussed, and amendments were included in the final map (which is the CLD of Figure 3); finally, Figure 3 as the model of The CLDs of the dynamic hypothesis have been determined.

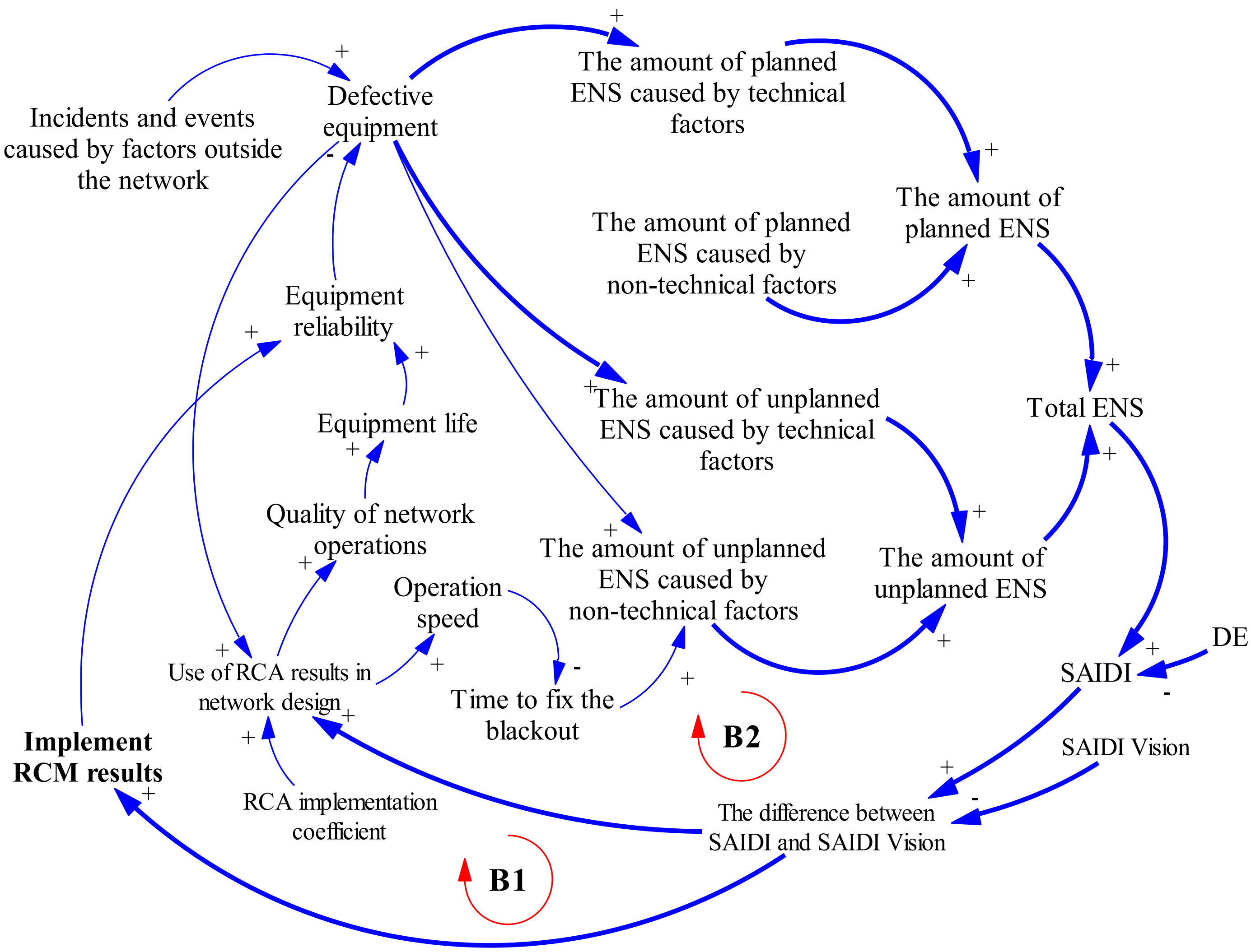

Figure 3. CLDs of dynamic hypothesis

Loop B1 with a negative impact on SAIDI in Figure 3 shows how increasing/decreasing the implementation of RCM results in decreasing/increasing the SAIDI behavioral process. Loop B2, with its negative impact on SAIDI, shows how implementing RCA results in network operation.

Increase/decrease incidents caused by factors outside the network will increase/decrease defective equipment. On the other hand, increasing/decreasing equipment reliability will decrease/increase the variable of faulty equipment. When a piece of equipment becomes defective, it needs to be repaired. The increase/decrease of these repairs, depending on the type and severity of the incidents, causes an increase/decrease in the amount of ENS in two categories: planned and unplanned. On the other hand, some ENSs in these two categories are caused by technical factors, and non-technical factors cause others. DE also influences SAIDI as an exogenous variable; their relationship ratio is increase/decrease to decrease/increase.

Finally, SAIDI and SAIDI Vision are compared, and their difference determines the values needed to change in performing RCM and RCA. RCM and RCA will change the reliability of the equipment, and as these two increase/decrease, the value of the reliability of the equipment will increase/decrease. In Figure 3, an attempt has been made to show the effects of RCM and RCA on SAIDI behavior in two loops, B1 and B2.

4.3. Formulation of simulation model

According to the CLD of the dynamic hypothesis (Figure 3) and the governing relationships between the model variables (Appendix-Table 1), the Stocks and Flows corresponding Diagram was created (Figure 4). In this modeling, by dividing the model into four subsystems and establishing a relationship between these subsystems, the behavior of the whole system was simulated based on Vensim DSS 6.4E software.

4.3.1. Subsystem that detects the difference between actual behavior and perspective

The first key loop in this model (Figure 5) is the negative feedback loop, which produces the primary goal-seeking behavior at a decreasing rate for SAIDI. As shown in the CLD in Figure 5, if the ENS variable increases/decreases, the SAIDI variable will increase/decrease more than it would otherwise. Then, by comparing the value of SAIDI with the value of perspective and discovering the difference between these two variables, the system determines the number of corrective actions needed to direct the system behavior toward the system goal. This set of corrective actions, ultimately with a negative effect on the ENS variable, causes a guiding effect on the SAIDI variable and directs its behavior towards the system's goal, the vision. The DE variable is considered an exogenous variable because it changes annually based on the consumption needs of subscribers and is not under the system's control.

Electricity distribution companies calculate SAIDI according to Equation 1:

$$SAIDI_{(minute/year)} = (ENS_{(MWH)}/DE_{(MWH)}) * 1440 * 365 \quad (1)$$

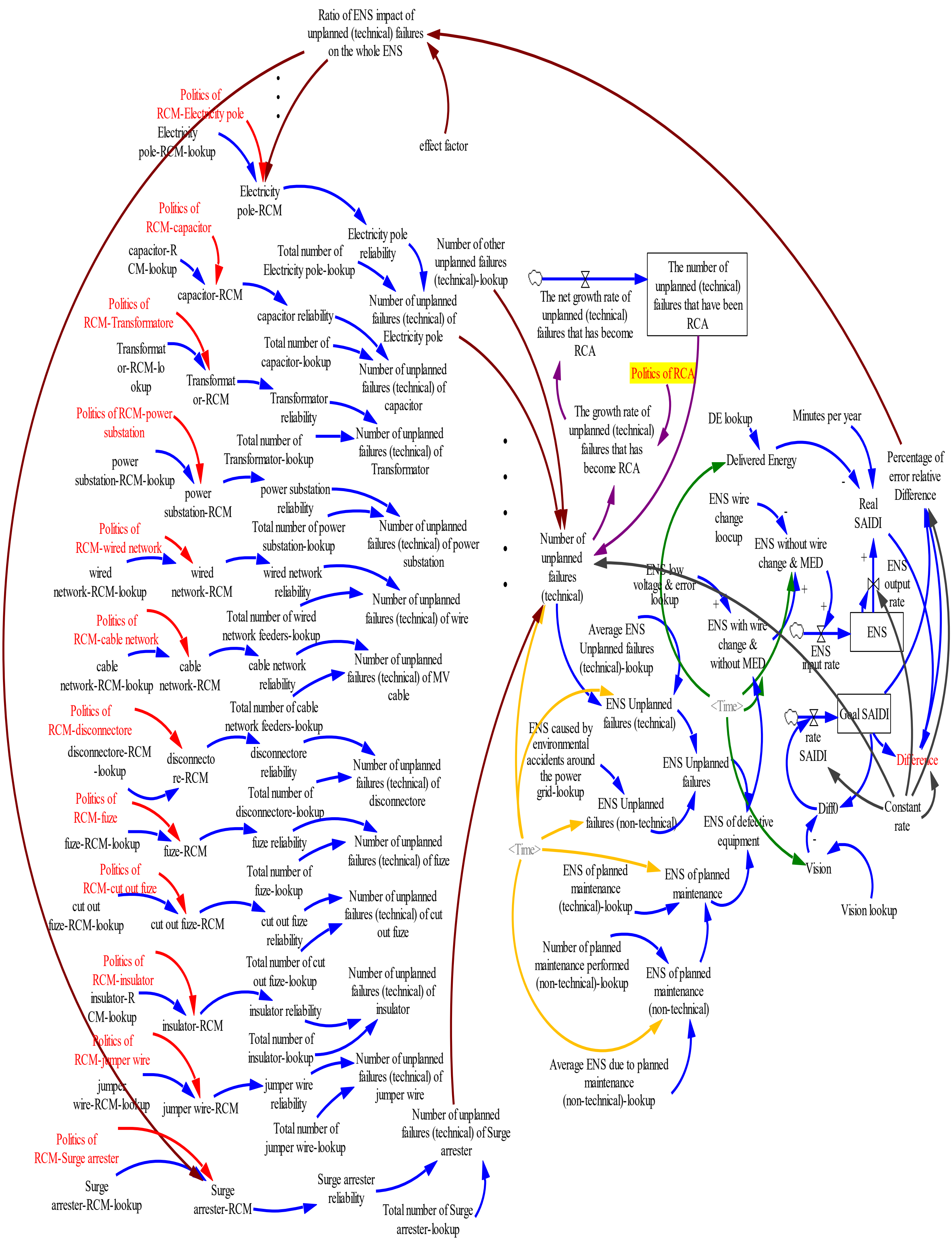

Figure 4. Stocks and flows diagram of the system

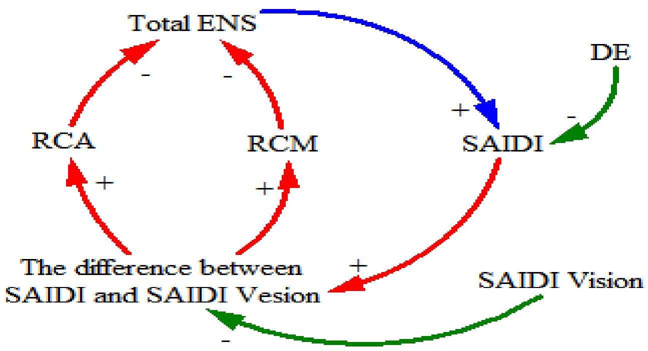

Figure 5. Negative feedback loop that produces SAIDI core behavior

By considering Figure 5 as the basis, the stock and flow model shown in Figure 6 was created. In this model (Figure 6), short-term annual goals have been designed to realize the 14-minute vision for SAIDI for each subscriber per year, and the company's correction plans in previous years have been adjusted accordingly. Therefore, the Vision variable is defined to show the desired target value each year to move toward the organization's vision. The role of loop B0 in the following model is to create the desired behavior for SAIDI, shown in the Goal SAIDI stock variable. Now, the desired behavior is compared with the actual and probable behavior of the system, which is generated in the Real SAIDI variable, and the detected difference is displayed in the Difference variable (Equation 2). The system's goal is to minimize this discrepancy during the realization of the vision.

$$Difference = Real\ SAIDI - Goal\ SAIDI \tag{2}$$

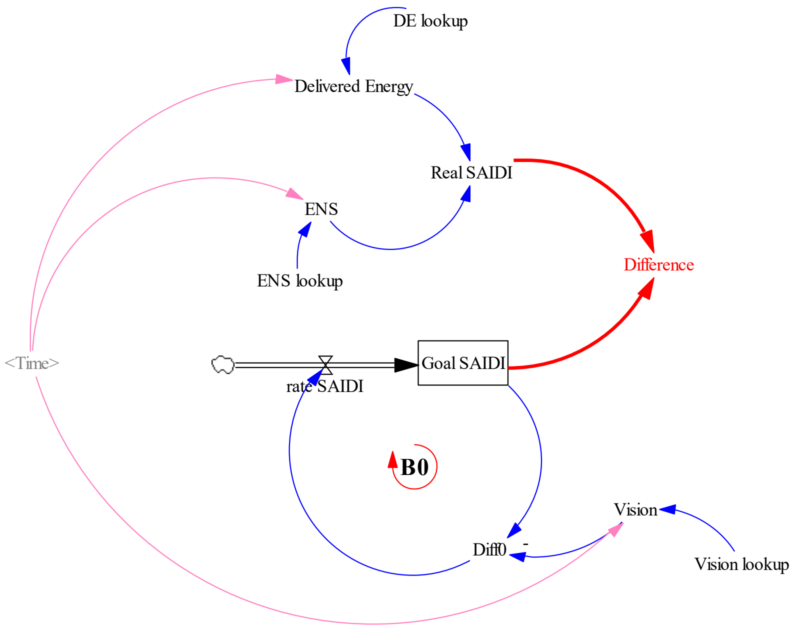

Figure 6. A model that shows the difference between the desired situation and the current and probable situation

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As shown in Figure 6, Real SAIDI is calculated with two variables, DE and ENS, the same as Equation 1. DE is an exogenous and out-of-control variable of the system, the values of which, at times, did not exist due to data shortages or data defects, are calculated approximately based on available data and linear regression estimates. The other variable is the "Percentage of error relative Difference", which represents the percentage of relative error (Equation 3) that Real SAIDI has with the Goal SAIDI (Figure 7).

$$Percentage\ of\ error\ relative\ difference\ = (Diffrence/Goal\ SAIDI) \times 100 \quad (3)$$

4.3.2. SAIDI subsystem

ENS has a combination of two components, which should be excluded from the calculations according to the SAIDI calculation guidelines related to the MEEDC perspective. "ENS wire change" and "ENS MED" are two components. After subtracting these two components, "ENS without wire change & MED" is considered input to the SAIDI calculation formula (Figure 7). In this project, to minimize and simplify the model, "ENS low voltage & error"(ENS of low voltage network and computational discrepancies in summarizing the data of the emergency database), which has a more negligible effect on SAIDI, was used as an exogenous variable; based on the model's records, the modeling of this section was refused. The variable "ENS of defective equipment" represents the total ENS in the medium pressure network, converted to the variable "ENS without wire change & MED", respectively.

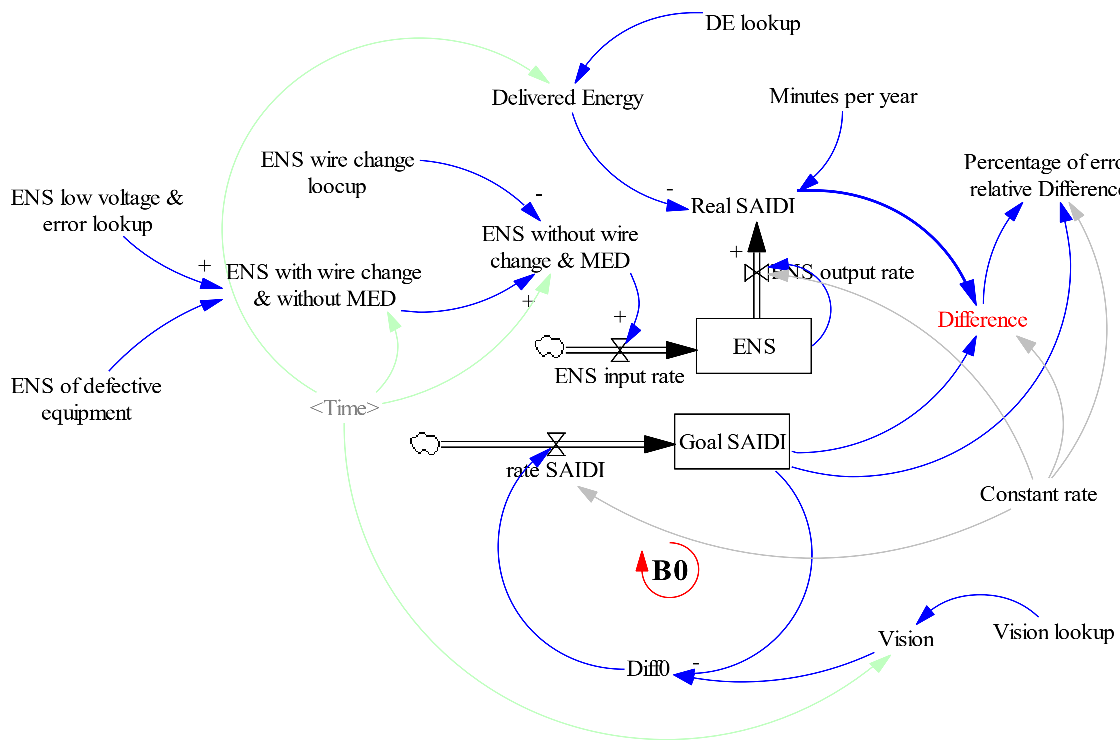

Figure 7. Separation of SAIDI calculation components

4.3.3. Subsystem of power outages caused by new failures

In the next step, the "ENS of defective equipment", made of ENS in the medium voltage network, is divided into constituent components based on the initial research approach. Figure 8 shows that "ENS of defective equipment" is divided into two main components, "ENS Unplanned failures" and "ENS of planned maintenance," In the continuation of these components, each with two components from a technical point of view and non-technical can be modeled. It was now necessary to determine which sub-component of the power outage each of the policies considered in the study would affect.

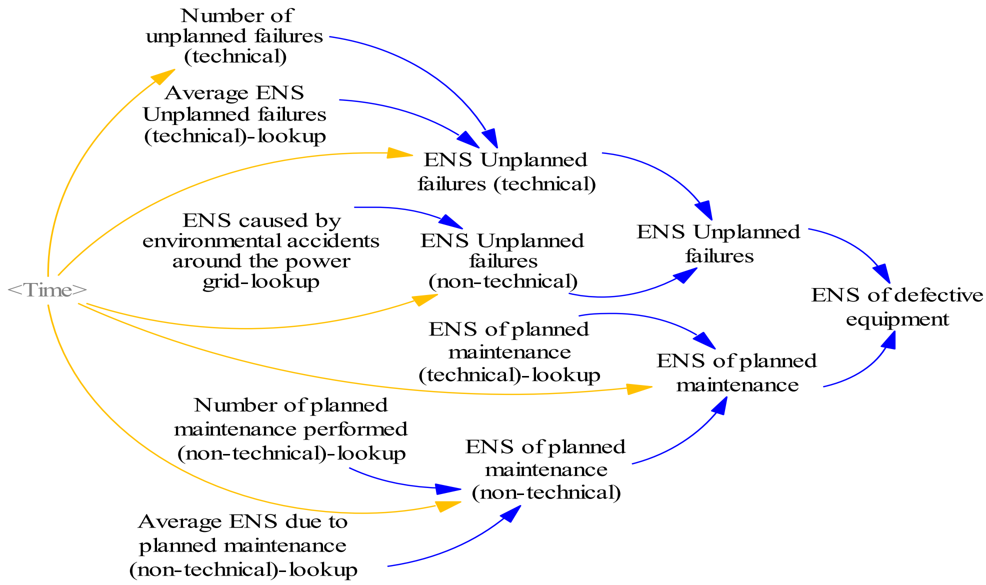

Figure 8. Components of "ENS of defective equipment"

4.3.4. RCM subsystem

Referring to Figure 3, it is clear that in the identified cyclical causal relationships, the variable "Implement RCM results" has a positive effect on "Equipment reliability," and "Equipment reliability" subsequently has a negative effect on "Defective equipment", and "Defective equipment" also has a positive effect on "the number of unplanned ENS caused by technical factors" on "the amount of unplanned ENS"; which is one of It is a sub-component of "Total ENS", which has a positive effect on the calculation of SAIDI. After calculating SAIDI, the difference with SAIDI Vision is calculated. The value obtained is used to modify the value of the "Implement RCM results" variable, which is the policy in this area, and this feedback loop is closed at this point. Therefore, it can be concluded that the "Implement RCM results" policy, by affecting the "Number of unplanned failures (technical)", can affect "the amount of unplanned ENS".

According to Figure 4, the "effect factor", the average ratio of "the number of unplanned ENS caused by technical factors" to "ENS of defective equipment", is introduced each year. The coefficient of this parameter with the variable "Percentage of error relative Difference" shows what percentage of the difference in Goal SAIDI and Real SAIDI is due to "the amount of unplanned ENS caused by technical factors"; This ratio is defined by the variable "Ratio of ENS impact of unplanned (technical) failures on the whole ENS".

4.3.5. RCA subsystem

The most significant effect of the policy of implementing RCA results is on the component "the number of unplanned ENS caused by technical factors". The more network equipment failures are analyzed and rooted out. The more RCA results are used in equipment design, redesign, and maintenance to prevent a recurrence, the lower the power outage (Figure 4). In order to make changes in RCA policy and to explain this policy to the model, the variable Politics of RCA, which is a number in the range [0,1], has been used. This variable indicates the percentage of policy implementation during simulation in the model.

4.4. Testing

In this research, validation has been performed to investigate the dimensional compatibility of the equations, test the limit conditions of the model, and create trust in the model, and the sensitivity of the system model has been analyzed. Testing and validation are the two essential notions of building confidence in system dynamics models. Testing means comparing a model to empirical reality for accepting or rejecting the model, and validation means establishing confidence in the soundness and usefulness of the model (Bala et al., 2017).

4.4.1. Behavior reproduction test

This test examines whether or not the model simulation, given the appropriate values, can simulate the past behavior of important variables with reasonable accuracy. The proper use of the behavior reproduction test is to uncover flaws in the structure or parameters of the model and assess whether they matter relative to the purpose (Sterman, 2000). Figure 9 shows the simulation results performed in two different modes simultaneously. This diagram shows that the model can display the actual reference behavior with the "Reference Mode Real SAIDI" curve and the simulated reference behavior with the "Current" curve. This diagram simulates the reference behavior of Figure . Of course, it calculates and plots the values of the "Current" curve before the 10th period due to insufficient information in MEEDC to simulate through the

Vensim software extrapolation system. As shown in the diagram, the two curves are almost identical from the fifth period onwards.

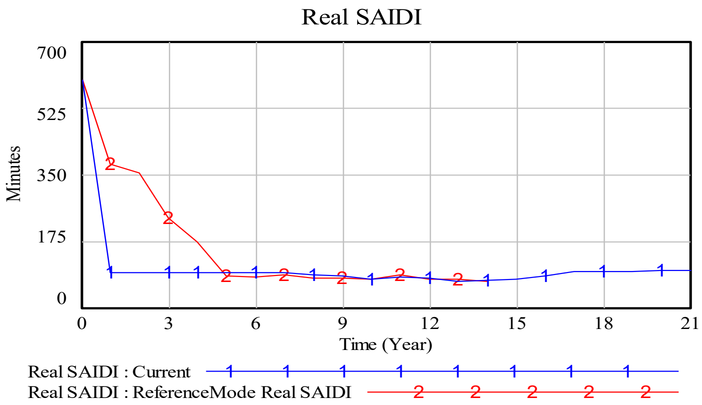

Figure 9. SAIDI behavior in reality and simulation

Table 2 shows the simulated values (Figure 9, curve 1) and the actual SAIDI (Figure 9, curve 2) from 10 to 14, which have complete and correct data in the databases. As it is apparent in the table, for the values before the 10th interval, Vensim software has extrapolated the values in the simulation without having complete input information, which is only the values up to the fifth time interval that are close to the real values. In this table, the average value of the absolute value of the error in the period from 10 to 14 for real and simulated values is calculated and placed. The MAE value equals 3.0388 minutes per year, which is a good value.

Table 2. SAIDI values in reality and simulation

Time (Year)	Real SAIDI	Reference mode real SAIDI
0	601.48	600
1	92.716	380
2	92.716	355
3	92.716	238
4	92.716	173
5	92.716	85
6	92.716	81
7	92.716	87
8	89.035	79
9	85.091	78
10	76.433	77
11	82.949	88
12	79.962	77
13	70.645	75
14	73.259	71
15	76.487	--
16	83.899	--
17	96.294	--
18	96.182	--
19	96.079	--
20	98.767	--
21	98.767	--
In the period from 10 to 14	(MAE) Mean Absolute Error	3.0388

4.4.2. Extreme condition test

This test evaluates and validates the model under extreme conditions. Extreme conditions are related to the time when, if the value of the model indices reaches its maximum or minimum limit, the model equilibrium is not disturbed, and the model variables do not exhibit misbehavior (Sterman, 2000). The model's main exogenous variables are the variables that apply the value of RCM and RCA policies to the equipment. These variables have a value of zero in the simulation default because these two policies have not been implemented in the organization yet, so they do not have past results to apply to the past results of the organization's behavior. Therefore, in the zero extreme conditions for these indices, the simulation result is the same as in Figure 9. Now, for example, by changing the index of RCM and RCA policies (Politics of RCA and Politics ... RCM variables) to the maximum value of 1, which is a sign of 100% application of these policies on equipment. the behavior of the system changes to the "Limit condition test" curve in Figure 10. As shown in the behavior of this curve, the equilibrium of the model is established, and the behavior of the behavioral model is correct and decreasing.

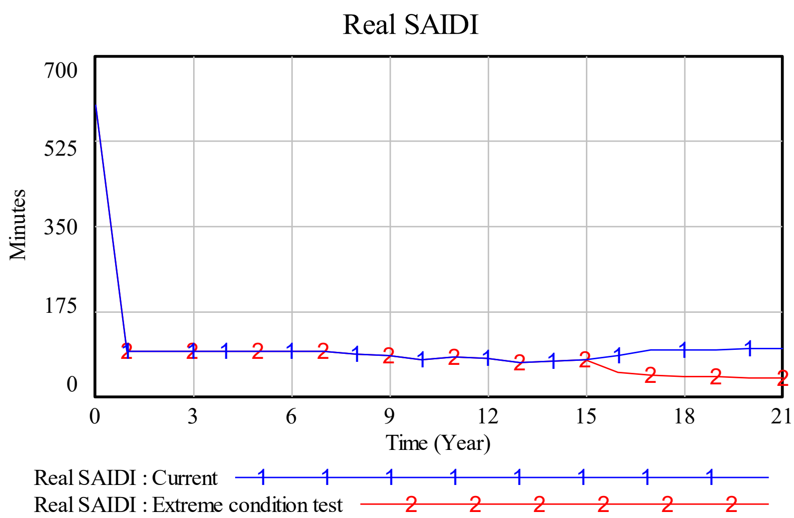

Figure 10. Extreme condition test

4.4.3. Sensitivity analysis

Since all models are wrong, it must test the robustness of the conclusions to uncertainty in the assumptions. Sensitivity analysis asks whether its conclusions change in ways necessary to purpose when assumptions vary over the plausible uncertainty range (Sterman, 2000). The sensitivity test indicates the model's sensitivity in simulating small changes in input indicators. With these small changes, the balance of the model should not be disturbed, and the behavior of variables should not change much. For example, suppose the RCM and RCA policy input indicators change to 0.01 each. In this case, the changes are shown in Figure 11, with the "Sensitivity test" curve indicating the model equilibrium and small and correct changes in the SIADI behavior curve.

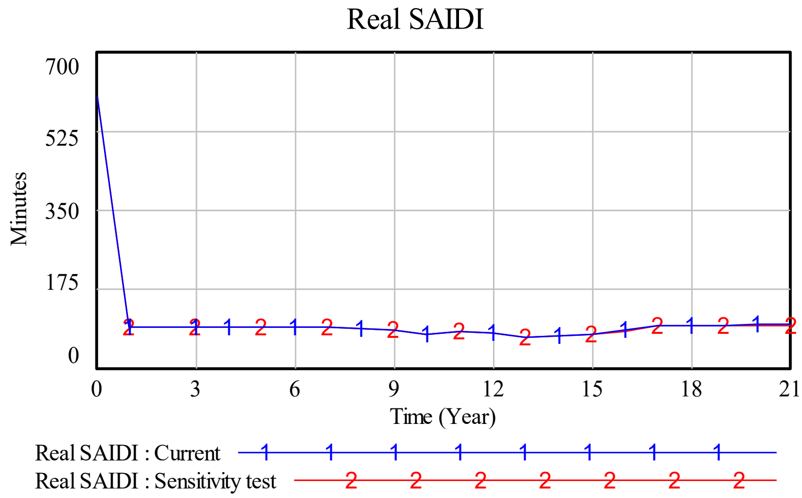

Figure 11. Sensitivity analysis

4.5. Policy design and evaluation

Policies' robustness and sensitivity to uncertainties in model parameters and structure must be assessed, including their performance under various alternative scenarios (Sterman, 2000). As can be seen from SAIDI's behavior in Figure 12 and its simulation results in Table 3, if the organization changes its policies to reduce ENS, only in the part of policies implementing RCM and RCA results on network equipment; and, in other cases, maintain existing policies; The amount of SAIDI will be affected, and will follow a decreasing trend; These policies, however, only affect the amount of "ENS Unplanned failures (technical)" (Figure 13), and the SAIDI value will eventually come close to the sum of the values of the other ENS components; In this simulation, the lowest value of SAIDI is obtained in "Scenario Optimize", with a value of 41.34 minutes per year (Table 3). It means that the SAIDI vision of 14 minutes per year cannot be achieved by the RCM and RCA implementation policy alone, and other policies that have a mitigating effect on other components of the ENS need to be explored, designed, and implemented.

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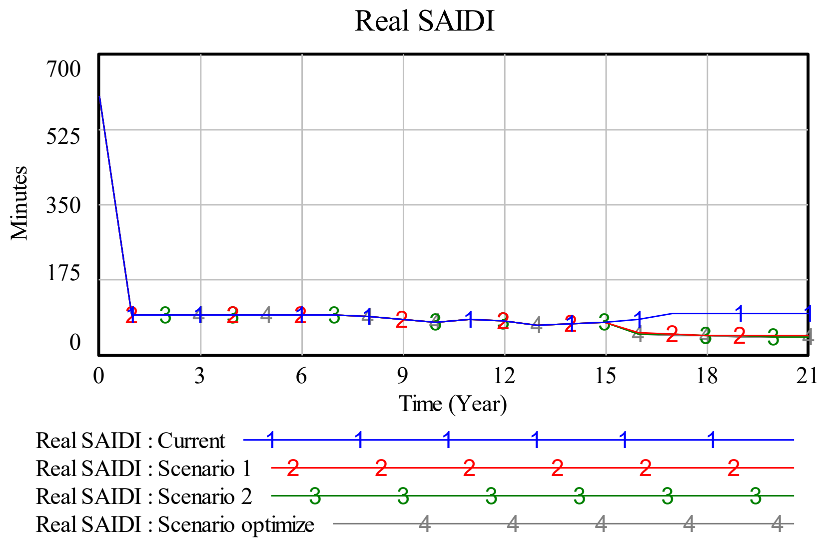

Figure 12. Results of RCM and RCA policies on SAIDI behavior

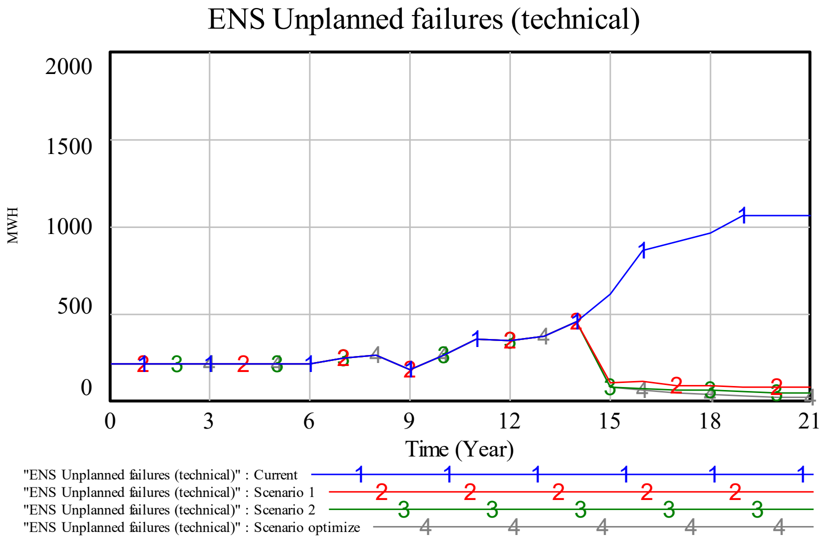

Figure 13. Results of RCM and RCA policies on "ENS Unplanned failures (technical)"

Table 3. Results of RCM and RCA policies on SAIDI at the end of 2026

Politics	Current		Scenario 1		Scenario 2		Scenario Optimize	
	The amount applied	Real SAIDI 2026	The amount applied	Real SAIDI 2026	The amount applied	Real SAIDI 2026	The amount applied	Real SAIDI 2026
RCA	0		0.05		0.1		0.2	
Electricity pole	0		0.5		0.9		0.9049	
Capacitor	0		0.5		0.9		0.1105	
Transformatore	0		0.5		0.9		1	
Power substation	0		0.5		0.9		0.4227	
Wired network	0		0.5		0.9		0.0911	
Cable network	0	98.77	0.5	44.45	0.9	42.66	0.8819	41.34
Disconnector	0		0.5		0.9		0.6171	
Fuze	0		0.5		0.9		1	
Cut out fuze	0		0.5		0.9		1	
Insulator	0		0.5		0.9		0.7774	
Jumper wire	0		0.5		0.9		0.9549	
Surge arrester	0		0.5		0.9		1	

Table 4 presents the results of simulating different scenarios in the defined values of different policies applied in Table 3 over 21 years. As shown in the "Current" scenario results column, SAIDI behavior will be bullish from the 14th period onwards if the status quo is maintained and there are no policy changes.

Table 4. Results of SAIDI in simulating different scenarios, under different policy conditions, over a period of 21 years

Year	Time (Year)	Real SAIDI			
		Current	Scenario 1	Scenario 2	Scenario Optimize
2005	0	601.48	601.48	601.48	601.48
2006	1	92.72	92.72	92.72	92.72
2007	2	92.72	92.72	92.72	92.72
2008	3	92.72	92.72	92.72	92.72
2009	4	92.72	92.72	92.72	92.72
2010	5	92.72	92.72	92.72	92.72
2011	6	92.72	92.72	92.72	92.72
2012	7	92.72	92.72	92.72	92.72
2013	8	89.04	89.04	89.04	89.04
2014	9	85.09	85.09	85.09	85.09
2015	10	76.43	76.43	76.43	76.43
2016	11	82.95	82.95	82.95	82.95
2017	12	79.96	79.96	79.96	79.96
2018	13	70.65	70.65	70.65	70.65
2019	14	73.26	73.26	73.26	73.26
2020	15	76.49	76.49	76.49	76.49
2021	16	83.90	52.11	50.55	50.22
2022	17	96.29	50.64	48.32	47.63
2023	18	96.18	47.67	46.43	45.39
2024	19	96.08	46.00	44.62	43.42
2025	20	98.77	44.55	42.96	41.68
2026	21	98.77	44.45	42.66	41.34

5. Discussion and conclusion

Given the importance of electricity supply continuously, from the perspective of the power distribution company and its customers, this study investigates the structure of SAIDI and the effects of implementation policies of RCM and RCA results on the behavior of this structure in the power distribution company, as a system in which policy-making affects many variables, as well as much feedback, Systems are affected, the dynamics method of systems is used.

Thurlby (2013), in the article "Managing the asset time bomb: a system dynamics approach," deals with the case study of a German power distributor who models using system dynamics tools and methods to understand and solve the problem of their asset time bomb, Developed. At its simplest, the asset time bomb is a threat that, when a critical set of assets reaches middle age, their performance declines rapidly, causing them to fail to achieve their desired performance goals. The organization in this study is one of the four most significant water and electricity companies in Germany, which manages urban and rural electricity distribution networks in the western part of the country. These networks were built in the late 1950s and early 1960s, and in the first decade of the 21st century, they were nearing the end of their life expectancy. Although the network's performance, whose key indicators were System Average Interruption Frequency Index (SAIFI) and SAIDI, is slightly better than the average of the German electricity industry, there was growing concern among the organization's network planners that existing asset management strategies would not maintain current performance levels with age. In essence, was the organization facing a potential asset time bomb? However, if existing strategies were to be changed, it would be necessary first to prove that the performance concerns were real by a forensic model and, second, to know the strategy changes that would solve them. In order to examine the first concern, which is related to the performance of the power grid, the researcher has modeled the two indicators, SAIDI and SAIFI, which were driven by the asset condition chains and, in turn, influenced the revenue stock and the rate at which assets deteriorated. This segment provided the other main feedback mechanisms in the model. The researcher also presents a 20-year SAIDI chart showing that if asset management policy does not change, there will be a real threat such as an hourly asset bomb, and its impact is imminent.

On the other hand, policy change can eliminate the threat and reduce the number of interruptions. Because of the above, in this study, the issue of the impact of changing Physical Asset Management policy on the SAIDI process has been modeled with a general and introspective view of equipment failure and the effects of Physical Asset Management subsystems and ENS on technical and non-technical dimensions, with planned and unplanned characteristics, and the relationships of these subsystems with each other and their interactions, As well as the effects of external destructive factors that occur as off-net events. They happen, it has not been noticed, so the research can be considered as having more abstract thinking than it can be considered as research with objective thinking.

By examining the research background, we can mention the study of Ghasemianfard and Moosavirad (2017) as a similar example of this research. Of course, this critique has entered the study, which has paid attention only to technical factors and accidents and has not paid attention to the effects of other factors.

According to these issues, in the present study, an attempt has been made to address the dynamics of the factors affecting SAIDI in the technical (planned and unplanned) and non-technical (planned and unplanned) dimensions and to create a holistic and systematic view of this issue; Therefore, it can be concluded that this research can be considered more extensive. The model presented in this study has considered unplanned ENS sub-components in both technical and non-technical dimensions and planned ENS in both technical and non-technical dimensions as factors affecting the ENS of medium-pressure networks. The models and previous research are complete. After creating a CLD with the opinion of experts and turning it into a Stocks and Flows Diagram, the effect of various factors in this system was determined. The model's validity was evaluated using three test methods: Behavior reproduction, Extreme condition, and Sensitivity analysis; the results of all tests indicate the model's accuracy in simulating the behavior of the primary variable. Since MEEDC's vision is to reduce SAIDI to 14 minutes per year, the effect of RCM and RCA policies in different scenarios on model variables was evaluated. The results showed that if the existing policies are not changed, the trend of SAIDI changes will increase. In case of a change of system approach, from non-implementation to implementation of RCM and RCA results (with optimized conditions), SAIDI will decrease from 73/26 at the beginning of 2020 to 41.34 minutes at the end of 2026. It is found that this time is the end of the deadline for the realization of the vision; therefore, it can be concluded that these policies have a mitigating effect on SAIDI, but they are not enough to realize the vision alone, and other policies need to be used.

In this study, to avoid the over-complexity of the model, only two policies, RCM and RCA, were selected, modeled, simulated, and analyzed from all MEEDC policies by the TOPSIS method with expert supervision. Therefore, adding other policies can improve the model presented in this research. Some areas that can complement the model presented in this research are modeling the role of network maneuvering systems, network equipment automation, workforce training, and hot-line operations. Also, since physical asset management tools are not limited to RCM and RCA of failures, By defining new variables and relationships in the model of this research, other tools (such as RCD (Reliability Centered Design) can be modeled as selected policies in other subsystems, and the model can be evaluated with these subsystems added. Other variables that affect SAIDI could also be included in this modeling; however, due to the over-complexity of the model, the lack of accurate information about them, and the lack of connection between some of them and the selected policies, they were omitted in this modeling. Among these influential factors can be mentioned the following: maneuvering in low voltage networks, the effect of logistics factors of incident groups and operation groups in faster elimination of blackouts, the use of distributed generation resources, and the use of mobile diesel generators, and the use of the skilled workforce, and supply resources financial. In addition to the above, examining the selected policies from other perspectives, such as reducing costs, energy losses, and equipment failure, is essential. Given the need to invest in the implementation of selected policies; Examining the effects of these policies in preventing energy waste and reducing ENS is essential in terms of economic productivity, and it should be borne in mind that the current model in the electricity industry confirms the positive effects of these policies, That is, there is a view that the implementation of these selected policies will reduce the ENS, and increase revenues from the sale of energy, for the power distribution company and the electricity industry. Also, due to the dependence on the production of goods, services, and all aspects of the life of people in society, electricity, reducing ENS, improves the quality of life in society and further prosperity of economic activities.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix

Appendix-Table 1. Variable types and related subsystem domains

Subsystem	Stock	Flow	Auxiliary
SAIDI	ENS; Goal SAIDI	ENS input rate; ENS output rate; rate SAIDI	Diff0; Difference; ENS with wire change & without MED; ENS without wire change & MED; Percentage error relative Difference; Real SAIDI; DE lookup; Delivered Energy; ENS low voltage & error lookup; ENS low voltage & error lookup; ENS wire change lookup; Vision; Vision lookup
power outages caused by new failures			Number of unplanned failures (technical)؛ Number of unplanned failures (technical) of MV cable؛ Number of unplanned failures (technical) of fuze ؛ Number of unplanned failures (technical) of Surge arrester ؛ Number of unplanned failures (technical) of Transformator ؛ Number of unplanned failures (technical) of jumper wire ؛ Number of unplanned failures (technical) of capacitor ؛ Number of unplanned failures (technical) of wire؛ Number of unplanned failures (technical) of disconnectore ؛ Number of unplanned failures (technical) of insulator ؛ Number of unplanned failures (technical) of Electricity pole ؛ Number of unplanned failures (technical) of Number of unplanned failures (technical) of power substation ؛ Number of unplanned failures (technical) of cut out fuze ؛ENS of defective equipment ؛ ENS Unplanned failures ؛ ENS Unplanned failures (technical) ؛ ENS of planned maintenance ؛ ENS of planned maintenance (non-technical); Number of planned maintenance performed (non-technical)-lookup; Number of other unplanned failures (technical)-lookup; ENS Unplanned failures (non-technical); ENS caused by environmental accidents around the power grid-lookup; ENS of planned maintenance (technical)-lookup; Average ENS Unplanned failures (technical)-lookup; Average ENS due to planned maintenance (non-technical)-lookup;
RCA	The number of unplanned (technical) failures that have been RCA	The net growth rate of unplanned (technical) failures that has become RCA	The growth rate of unplanned (technical) failures that has become RCA؛ Politics of RCA
RCM			Surge arrester-RCM ؛ Transformator-RCM؛ jumper wire-RCM ؛ capacitor-RCM ؛ cable network-RCM ؛ wired network-RCM ؛ fuze-RCM ؛ disconnectore-RCM ؛ insulator-RCM ؛ Electricity pole-RCM ؛ power substation-RCM ؛ cut out fuze-RCM ؛ jumper wire reliability ؛Surge arrester reliability ؛ Transformator reliability ؛ capacitor reliability ؛ cable network reliability ؛ wired network reliability ؛ fuze reliability ؛ disconnectore reliability ؛ insulator reliability ؛ Electricity pole reliability ؛ power substation reliability ؛ cut out fuze reliability ؛ Ratio of ENS impact of unplanned (technical) failures on the whole ENS effect factor; Politics of RCM-Surge arrester; Politics of RCM-Transformatore; Politics of RCM-jumper wire; Politics of RCM-capacitor; Politics of RCM-cable network; Politics of RCM-wired network; Politics of RCM-fuze; Politics of RCM-disconnectore; Politics of RCM-insulator; Politics of RCM-Electricity pole;

	Politics of RCM-power substation; Politics of RCM-cut out fuze; Surge arrester-RCM-lookup; Transformator-RCM-lookup; jumper wire-RCM-lookup; capacitor-RCM-lookup; cable network-RCM-lookup; wired network-RCM-lookup; fuze-RCM-lookup; disconnectore-RCM-lookup; insulator-RCM-lookup; Electricity pole-RCM-lookup; power substation-RCM-lookup; cut out fuze-RCM-lookup; Total number of cable network feeders-lookup; Total number of capacitor-lookup; Total number of cut out fuze-lookup; Total number of disconnectore-lookup; Total number of Electricity pole-lookup; Total number of fuze-lookup; Total number of insulator-lookup; Total number of jumper wire-lookup; Total number of power substation-lookup; Total number of Surge arrester-lookup; Total number of Transformator-lookup; Total number of wired network feeders-lookup