Influence-ladder diagrams as a Method for Teaching and Designing Instrumentation and Automation

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Abstract. Living society is surrounded by various automatic systems. The system design process is one of the important stages in designing an automated system. This indicates the importance of educating engineers capable of designing systems. However, in the learning process, there are difficulties in giving students an understanding of how to compile a ladder diagram with clear steps. There are difficulties in translating the requirements for the electrical system into a ladder diagram. Through this paper, we propose the Influence ladder diagram as a diagram that helps the process of teaching ladder diagram design. This diagram can be used for the teaching process as well as for the actual system design.

1. Introduction
The development of automation is growing rapidly [1], one of which is the application of cloud robotics [2]. One aspect that is affected is employment [3]. One of the competencies that deserves to be trained at a time when various human jobs are starting to be replaced by robots, is the ability to design the robot itself, or design an automatic system.

In designing an electrical diagram, sometimes the designer is given a case, then asked to design a system that supports the automation requirements. A requirement generally uses human language and logic [4]. This human narrative needs to be logically modeled. However, no method has been found that guides the process of translating the narrative into a ladder diagram.

The existence of this method is important because it will make it easier for the designer to design the ladder diagram. Besides that, the ladder diagram is a model. The model may not be valid enough. With a rigid method, the validity of the ladder diagram can be maintained.

In the context of teaching, there is a clear method in guiding the change from narrative requirement to ladder diagram, which will make it easier for teachers to convey knowledge to students. Students will also find it easier to understand if the method is clear enough. Tacit knowledge is transformed into explicit knowledge making it easier for communicants to absorb knowledge.

Some previous research has tried to discuss this ladder diagram. What has developed quite recently is the integration of Ladder Diagram and Petri nets [5][6][7]. Other research has tried to examine something close to this paper, namely using a model driven engineering in designing PLCs [8]. There is also a paper explaining the history of ladder diagrams dating back 100 years [9]. Meanwhile, in the context of teaching automation, there are also several studies that examine it. There is research that examines the application of Blended Learning at the University [10]. There is also research that discusses student-friendly teaching patterns in understanding automation [11], using pseudo software [12], dealing with mechatronics [13], and several other studies. However, we still haven't found any
research that tries to guide explaining the logic of cause and effect in designing ladder diagrams in the context of integrated system design. Therefore, this research tries to propose a method which is expected to make it easier for students to understand the logical process of design requirement to create ladder diagrams.

2. Method and Algorithm
The method used in this design is to combine several methods into one. Influence diagram is a method of designing a mathematical model. Influence diagrams are used in management science and are also adopted for industrial engineering science [14]. As the object of Management Science and Industrial Engineering, the object of the Influence diagram is also a complex system. There are several kinds of complex systems [15]. One of the systems included in a complex system is an Integrated System. An integrated system is a system that has man, machine, material, and method components [16]. Influence diagram illustrates the logic of cause and effect between variables in the system. These attributes are suitable for use also in automation systems.

Even though the electrical diagram system is not an integrated system, several cases that cause the need for electrical system design are problems that arise in a complex system or in an integrated system. The system is designed to be automatic in order to help the performance of humans. So that this electrical system is closely related to integrated systems.

We try this method in class. Students are given examples and then asked to work independently. After each stage has been taught, students are asked to do the exercises according to what has been taught at that stage, before moving on to the next stage. In addition to being taught using direct explanations in class, students also get video recordings so they can repeat them at home.

Then this research process can follow the following flow
1. Evaluation of Learning
2. Designing new teaching methods
3. Application of new teaching methods
4. Evaluation of learning with new teaching methods

3. Result and Discussion
Case study about Temperature Control: A temperature control system consists of many thermostats. The system operates three heating units. Below 20°C three heaters are to be in ON state. Between 20°C - 25°C two heaters are to be in ON state. Between 25°C - 30°C one heater is to be in ON state. Above 30°C all heaters are to be in OFF state, there is a safety shutoff in case any heater is operating by mistake. A master switch turns the system ON and OFF.

A diagram depicting the influence between variables or values in the system. In order to design an influence-ladder diagram, first identify the Input (control) and Output (Load) components. Based on the cases discussed, the Load is
1. (H1) Heater 1
2. (H2) Heater 2
3. (H3) Heater 3
Meanwhile, the control is
1. Temperature Limit Switch 1 (TLC 1)
2. Temperature Limit Switch 2 (TLC 2)
3. Temperature Limit Switch 3 (TLC 3)
4. Push Button On (PB On)
5. Push Button Off (PB Off)

![Diagram showing control and load relationship](image)

**Figure 2. Load And Control**

The next stage in implementing influence-ladder diagrams is to study the relationship between each control and each load. This relationship is illustrated using a diagram which we call the influence ladder diagram. The icon that is the cause is positioned above the icon that is the result. Because control affects load, it is positioned above load. The influence relationship is depicted using arrows. As shown in Figure 2, PB on and PB Off affect the entire load. This is because in the case described, Push Button On and Push Button Off are the main controllers whether the system is running or not. Whereas TLC 2 only affects H2, this is because in the case it is explained that the temperature sensor determines which heater two will function or not.

Then after the influence-ladder diagram was designed, the next step was to compile the initial ladder diagram. The initial ladder diagram is based on the causality that was explained in the influence ladder diagram. The rules for drawing ladder diagrams are still in accordance with the basic rules, namely that there is a maximum of one load in each row. Then the design of the ladder diagram begins by drawing one load each on each line. Each load is affected by several controls. What are the influencing controls in that line, refer to the influence ladder diagram. For example, H2 is influenced by PB On, PB Off, and TLC 2. This is because in the influence-ladder diagram, the arrows pointing to H2 come from PB On, PB Off, and TLC 2. PB On is on 3 load lines and affects all three loads. This is in line with the influence ladder diagram where PB On gives arrows to the three loads.
The next stage is optional. The designer can simplify the diagrams that have been designed. Simplification of the influence ladder diagram is carried out simultaneously with simplification of the ladder diagram. One of the complexities that can be seen in the initial design is that PB On and PB Off affect all loads so that the arrows are made very complicated. Then it can be simplified to make load that is intermediate, namely CR 1. As seen in figure 3, PB On and PB off affect Load CR 1. Then CR 1 affects all other loads. The causal relationship formulated in Figure 2 is still in line with what is written in Figure 3, but with a simpler writing. This change also occurs in the ladder diagram. First bolted a new load, namely CR 1. On the CR 1 line, there are PB On and PB Off controls. Meanwhile, because CR 1 affects all other loads, CR 1 as a control also appears on each load line.

As shown in figure 4, The next process is a process that is commonly done even without using the influence ladder diagram method. The next process is to modify whether each control is normally open
or normally closed. This can be done directly on the ladder diagram, without the need to change the influence ladder diagram. The Influence Ladder diagram only explains how the connection is between each control and each load. As for the nature of control, it is not regulated and is not described in the influence ladder diagram.

![Influence Ladder Diagram](image)

**Figure 5. Load And Control**

The last stage is defining the instruments used for each load and control. For example, as seen in figure 5, the TLC 2 control is changed to Temperature Level Switch. This process is also not related to the design of influence ladder diagrams.

4. **Conclusion**

In other classes, this method is not used. Based on the assessment of the teacher, this method proved to be more understandable to students because it had clear explanatory stages. Student difficulties and mistakes in the design process can also be minimized.

Influence ladder diagrams are able to map out the logic that underlies a requirement for designing electrical systems and automation systems. Influence-ladder diagrams also complement one missing rung in ladder diagram design.

Some further research can be done. One of the researches that can be done is to test the effectiveness of this teaching method quantitatively in the student's academic assessment. In addition, it can also be evaluated the effectiveness of this method for designing large-scale ladder diagrams which certainly have a higher level of complexity.

**References**

[1] M. R. Endsley, “Automation and situation awareness,” in *Automation and Human Performance: Theory and Applications*, 2018.

[2] B. Kehoe, S. Patil, P. Abbeel, and K. Goldberg, “A Survey of Research on Cloud Robotics and Automation,” *IEEE Trans. Autom. Sci. Eng.*, 2015, doi: 10.1109/TASE.2014.2376492.

[3] J. Bughin *et al.*, “A Future That Works: Automation, Employment, and Productivity,” *McKinsey Glob. Inst.*, 2017.

[4] A. Barkalov, L. Titarenko, and M. Mazurkiewicz, “Programmable Logic Controllers,” in *Studies in Systems, Decision and Control*, 2019.

[5] G. B. Lee, H. Zandong, and J. S. Lee, “Automatic generation of ladder diagram with control...
Petri Net,” *J. Intell. Manuf.*, 2004, doi: 10.1023/B:JIMS.0000018036.84607.37.

[6] M. V. Moreira, D. S. Botelho, and J. C. Basilio, “Ladder diagram implementation of Control Interpreted Petri Nets: A state equation approach,” 2009, doi: 10.3182/20091006-3-es-4010.00016.

[7] D. F. Bender, B. Combemale, X. Crégut, J. M. Farines, B. Berthomieu, and F. Vernadat, “Ladder metamodeling and plc program validation through time petri nets,” 2008, doi: 10.1007/978-3-540-69100-6-9.

[8] J. M. Farines, M. H. De Queiroz, V. G. Da Rocha, A. M. M. Carpes, F. Vernadat, and X. Crégut, “A model-driven engineering approach to formal verification of PLC programs,” 2011, doi: 10.1109/ETFA.2011.6058983.

[9] N. P. Johnson and P. Denes, “The Ladder Diagram (A 100+ Year History),” *Am. J. Cardiol.*, 2008, doi: 10.1016/j.amjcard.2008.02.085.

[10] W. Yan, “Design of PLC Technology Courses Based on Blended Learning in Colleges and Universities,” 2019, doi: 10.1007/978-3-030-35095-6_7.

[11] F. Soares, C. P. Leao, and P. M. Oliveira, “A student-friendly approach in teaching/learning theoretical concepts in automation,” 2017, doi: 10.1109/MED.2017.7984296.

[12] S. E. E. Peter, “The learning and teaching of PLC programming pseudo-software,” 1993.

[13] S. He, H. Rahemi, and K. Mouaouya, “Teaching PLC programming and industrial automation in mechatronics engineering,” 2015, doi: 10.18260/p.24820.

[14] H. Daellenbach, D. McNickle, and S. Dye, *Management Science*. 2012.

[15] C. Harrell, R. Bowden, and B. K. Ghosh, *Simulation using promodel*. McGraw-Hill Higher Education, 2000.

[16] J. Matson, J. Mozrall, D. Schaub, and P. Patterson, “An industrial engineering body of knowledge?,” 2007.