The DSS for Design Electrical and Communication System in Internal Buildings

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***Abstract*-The objective of this research is to develop a Decision Support System (DSS) for design electrical and communication system in internal buildings based upon expert system concept. This method can reduce designing time and designing errors from low-experienced staff and problems from frequently revised architectures according to customer requirements. The process of the DSS development has been started from analyzing various theories which are used for designs including with necessary data for consideration of factory electrical system design comprised of the electrical lighting system, the electrical power system and the electrical communication system. The whole knowledge has later been brought to design and develop the computer program by using C# Sharp Develop linked to nanoCad and MS-Excel Programs to make the system be conveniently utilized. Results from the experiments of a pilot project state that before applying the expert system program, design activities of electrical engineers generate the average error at 3.05 points with 5.98 hours per activity; and after applying the expert system program, the error from the designs can be reduced 46.15% with only 3.97 hours per a design activity. The highlight of this DSS is that the program can support customer drawing modification and enhance learning or training for low-experienced staff. A case study, recommendations, limitations, and further research are also presented.**

***Keywords*– Decision Support System, Expert System, Computer aided Design, Electrical System Design.**

I. INTRODUCTION

Nowadays, companies in all sectors examine ways to reduce costs, shorten product development times, and manage risks [4], especially subcontractor companies in factory electrical design business which received project orders from huge companies. They are attempted to survive by managing various operational functions such as reducing project designing time, operational cost, employee's wage, expertise's wage, fines for project delay, etc; while it seems to be contradictory with their effort to increase margin by handling more projects and improving the quality for competitions. Moreover, a critical obstacle of electrical system that subcontractors accepting orders from large construction contractors is those subcontractors always submit their preliminary designs and cost estimations promptly and accurately for making decisions of project owners to invest. Electrical systems remain important to be cost estimated for these project constructions with utmost accuracy. Normally, well electrical system design requires professional engineers with high experiences; unfortunately there is still a very lack of such engineers in electrical design systems for industry. Therefore, the current obstacle is, in order to design these systems, they have to employ such non-experienced engineers to do these jobs instead and mainly caused the design errors which affect the project time waste of design revisions and cost estimations including the delayed delivery of electrical system design plans to customers or big construction contractors. Furthermore, various issues result in the indirect impacts of delayed drawing delivery such as contractors' rejects of claim expense on design errors by passing many fines to subcontractors. From a lack of experts, high impact in design errors and delays causes subcontractors to extremely need solutions or computer software to support electrical system design activities more efficiently. Hence, it is critical to develop a decision support system which will be able to create a positive impact on many perspectives; for the example, to speed up the process of decision making, to speed up problem solving of design project, to facilitate interpersonal communication skills, to promote learning or training, to create a competitive advantage over competitors, and to help automate managerial processes, etc.

From the current obstacle of the subcontractor designing firms, this paper has investigated such kind of problems solving and it has been found that DSS by using Expert System (ES), which is to design computer software for solving various problems instead of human labor by gathering knowledge from formula and expert's knowledge and store as knowledge base, could implement as reviewed and classified by Liao [7] and also various applications such as Olugu and Wong [11], Jaques et al [5], Ochoa and Capeluto [10], etc. This research is consequently aimed to develop the decision support system program based upon expert system concept to support engineer designers to operate their works in designs of electrical systems for industrial factories more accurately and including to reduce steps of calculation, data search and design period which make decisions become faster and more correctly in accordance with theoretical principles of electrical engineering designs and safety engineering design. The following section presents model of decision support system for designing the electrical industrial factory. The designing program for the decision support system is presented in Section 3. Section 4 assesses this model by a case study of design factory electrical system in Thailand. Section 5 draws the conclusions and Section 6 presents the limitation and recommendations.

II.MODEL OF A DECISION SUPPORT SYSTEM

The study on literature reviews defined the term "expert system" refers to a computer program that is largely a collection of heuristic rules and detailed domain facts that have proven useful in solving the special problems of some technical fields. Expert systems (ES) is a branch of applied artificial intelligence (AI), and were developed by the AI community in the mid-1960s [7]. The basic idea behind ES is simply that expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer. Then like a human consultant, it gives advices and explains, if necessary, the logic behind the advice [14]. Expert systems has been divided into two main methods, i.e. a rule-based ES which contains information obtained from a human expert, and represents in the form of rules, such as IF–THEN, and Knowledge-based systems (KBS) which is human-centered. Regarding the primary data collections from interviewing subcontractors who supply designs and installations services of electrical systems for industrial factories in Thailand, and related researches papers, it can be stated that a few designs of electrical systems for industrial factories use expert system software as solutions. This might be caused by the difficulty to find experts and specialized knowledge for development program. However, another research also states that there is a usage of the expert system to solve concerned problems such as Rahman and Hazim [12], whom is analyzed a newly developed site-independent technique for short-term load forecasting. Gagne et al [2] proposed an interactive, goal-based expert system for day lighting design, intended for use during the early design phases. Sahin et al [17] studied a statistical analysis of hybrid expert system approaches and their applications. They reported that many different applications of expert system have emerged for hybrid expert systems but the main increase is in industrial applications. Engin et al [1] presented rule-based expert systems for supporting the scholarship recommendation of university students. Muhammad et al [9] conducted the research by the name of “A Review on Expert System and its Applications in Civil Engineering” which was presented about applications of the expert system in civil engineering to make decisions of designs for avoiding waiting time of construction managements. It used the intelligence of the computer software to solve complicate problems as smart as experts do. Some of ES applications which are implemented by Rule-based systems include the following: electronic power planning, automobile process planning, system development, knowledge verification/validation etc. as many concluded by Liao [7].

Furthermore, an the important benefit of using ES is the training via expert system program, some of the most important are: the ability to train non-experienced staff on malfunctions; the ability to train personnel on actual plant events; a broader range of personnel receiving effective training; and individualized instruction or self-training being performed effectively on simulation program designed with these capabilities such as Mondragón et al [8] have presented the power plants simulators with an expert system to train and evaluate operators, etc. Although, ES is widely applied in many directions, the core concept of expert system architecture is illustrated in Figure 1.

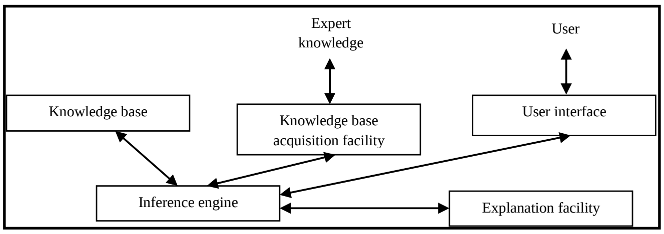

Fig. 1 Architecture of a simple expert system

As illustrated in Figure 1, basic structure of an expert system is the knowledge base that stores all relevant information, data, rules, cases, and relationships used by the expert system. A knowledge base can combine the knowledge of multiple human experts. A rule is a conditional statement that links given conditions to actions or outcomes. A frame is another approach used to capture and store knowledge in a knowledge base. It relates an object or item to various facts or values. A frame-based representation is ideally suited for object-oriented programming techniques. Expert systems making use of frames to store knowledge are also called frame-based expert systems. The methodology of DSS with expert system technique can be classified as:

- Inputs: factors, numbers, and characteristics to analyze
- User knowledge and expertise: Inputs requiring manual analysis by the user
- Outputs: transformed data from which DSS "decisions" are generated
- Decisions: results generated by the DSS based on user criteria

According to the industries' obstacle, literature reviews and benefits of the DSS with expert system method which have been mention in the previous section, the expert system program which can reduce design errors from non-experienced staff and problems from frequently revised architectures according to customer requirements, has been performed. The challenge for the authors was to consider the core needs of computer program design whilst minimizing cost and ensuring the integration of electrical engineering design aspects within the time constraints of plant layout development project. This programming design system utilizes NanoCad, free computer aided design software [16] as an electrical system design platform; the process to integrate Factory Electrical Engineering Design restrictions and problems into the ES decision support development is as following;

2.1 First stage, this Expert System (ES) model has been developed based upon “Electrical Engineering Design Manual” in Plant Layout design implementation and merged with the communication design system including local area network (LAN) system, fire alarm systems and public address into a knowledge base of expert system program as illustrated in simple expert system architecture (figure 1).

2.2 Second stage, appropriate information is included in programming design phase for electrical construction and project planning phase is performed based upon Concurrent Engineering (CE). This concept can primarily increase competitiveness by shortening the lead-time, and improve quality and cost such as CE applications by Harrington et al [3] approached a concurrent engineering to support process plant design decisions with respect to lifecycle concerns, and can reduce design iteration and compromise. Yang and Xue [15] introduced a concurrent engineering-oriented design database representation model (CE-DDRM) for supporting various life-cycle aspects as indicated in Figure 2.

2.3 Afterwards laws and regulations relating to electrical plant design review are integrated into the analysis by CE team, such as electrical lighting systems, and other standard requirements for each industry concern to meet customers' and market's needs, as well as product trends to study details of concepts of the ordered project in electrical system and construction designs in order to implement the safety conceptual lighting system design.

2.4 Designing lighting illumination systems, emergency light systems, exit sign light systems including with electrical receptacle systems to run circuit numbering for applications in specifying designs of panel load schedules is shown in fig.3.

Fundamental example equations of lighting systems are collected into basic knowledge of the expert systems such as calculations of lighting systems by Lumen method, lamp selection, reflection light calculations, etc. According equation (1-3), it specifies N as bulb amount, A as area (square meter), E as illuminance (lux), L as luminous flux of a bulb (lumen), MF as maintenance factor, and CU as coefficient of lamp utilization.

$$N= (AxE)/(LxMFxCU) \qquad (1)$$

Generally, the maintenance factor (MF) is comprised of 2 parts; one is lamp lumen depreciation (LLD) which is average illuminance light per initial illuminance light of a bulb which is declared by its manufacturer, the other is luminaire dirt depreciation (LDD) which depends on environment and cleanness. The meaning of coefficient of utilization (CU) is ratio of lamp light and reflection light from ceilings, floors including with walls as incident light on a work desk per emission light from bulbs. Basically, CU can be found from tables of CU declared by manufacturers. Before using these tables, the room cavity ratios (RCR) should be first known according to equation (2).

$$RCR= ((5xHx (L+H))/ (LxW) \qquad (2)$$

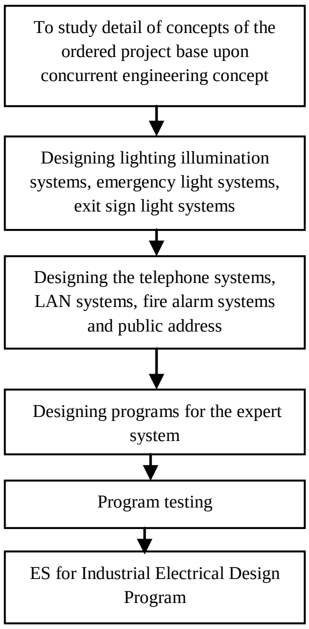

Fig. 2 decision support process for developing electrical lighting systems concepts

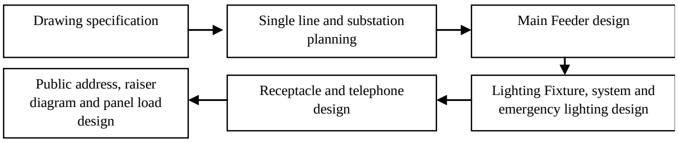

Fig. 3 processes of electrical power system designs.

For any lamp from USA, Europe or Japan, we can get the "Room Index (K)" from equation (3),

$$K= (L+H)/(H x(L+H)) \qquad (3)$$

where L is the room length (meter), W is the room width, H is the height above the work desk (H) such as 3 m room height and 2.2 m work desk height gives H equal to 2.2 m. See the fig. 4; it is an example of a table of CU of a Japanese manufacturer.

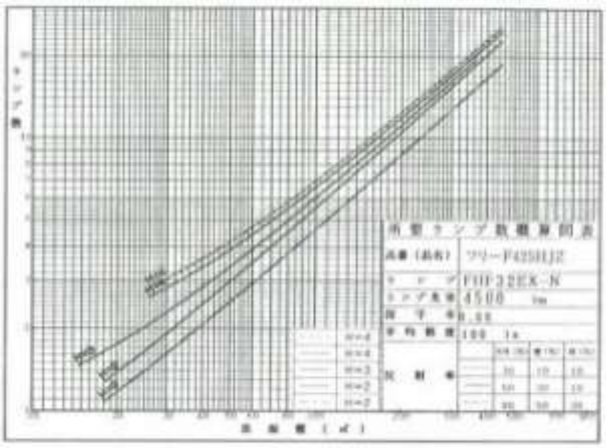

Fig.4 the example table from a manufacturer

2.5 At this stage, electrical communication system designs, i.e. telephone systems, LAN systems, fire alarm systems and public address systems are comprised and considered to design in the expert system. All systems are brought into analysis drawing points and riser diagram according to fig.5.

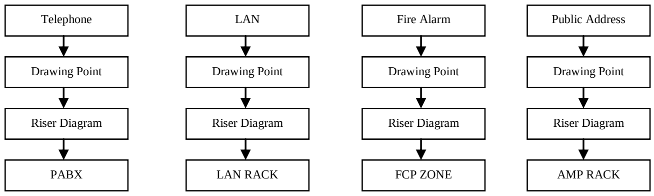

Fig.5 processes of electrical communication designs.

In this section, the expert system program architecture and requirement information for creating the program is considered. Section 3 designing program for the DSS consisted of the programming language, user interface and capability as the linkage with the other software is presented.

III.DESIGNING PROGRAM FOR THE DECISION SUPPORT SYSTEM

In the research, C# SharpDevelop (Open Source) is selected to use [13] which is priceless, processing fast, low hardware resource utilized and application tool co-developed with nanoCad 5, which is a free CAD software having a fairly similar interface with AutoCAD. Due to its inference engine and the configuration of electrical design, the expert system is able to modify the factory electrical design process because it can insert malfunctions, modify values of selected process and control variables, and change the status of the simulation without the intervention of an instructor. The expert system is embedded within the nanoCad program and also capability to transfer to Microsoft Excel, as shown in fig. 6-8.

In order to experiment the program designing electrical systems for an industrial factory whether it is practical and efficient to implement, the following steps shall be applied.

1) Training users for primary knowledge of the DSS program operation in designing electrical systems
2) Comparing the classical calculation method without the program and application of this developed DSS program
3) Collecting data and conclude the result comparison

IV. EXPERIMENTAL

The research was conducted in collaboration with an electrical system design for sub-contracted company in Thailand. The main business activities of the company are the design, consult, and construction of electrical facility equipments. In order to test the program in analyzing the design errors of electrical system, a young designer engineering team of 5 staff from a private company was selected to design 17 activities of an electrical system. Each engineer handles the operational design in different stages as follows; the first engineer design activities 1-5, the second one design activities 6-8, the third one design activities 9-10, the fourth one design activities 11-13, the last engineer design activities 14-17, and then the operation time and design failures points were recorded as illustrated in figure 9 with details in Table 1.

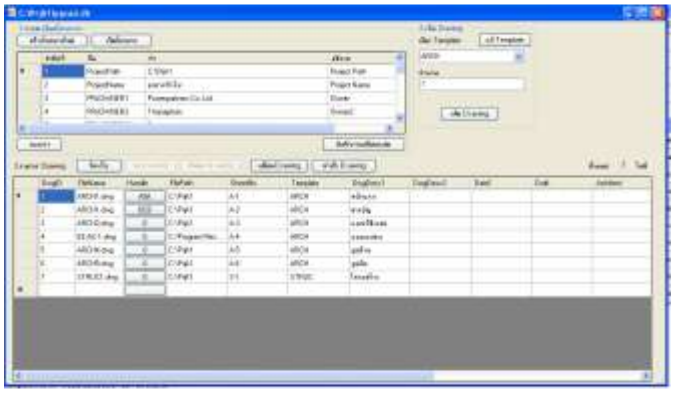

Fig.6 the session of program operation (User Interfaces)

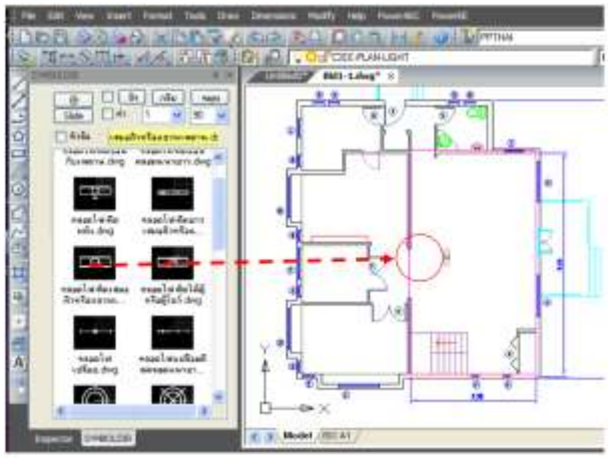

Fig. 7 the session of co-operation of the expert system program and nanoCAD 5

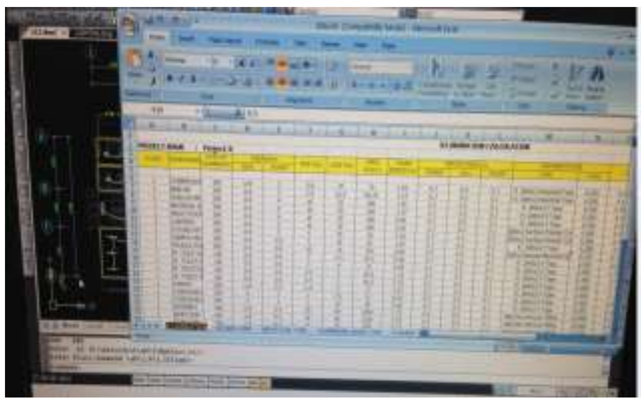

Fig. 8 the session of co-operation of the expert program with database transferred to Excel.

Fig. 9 the DSS program testing by an engineering team

TABLE I
COMPARISON DATA OF MANUAL DESIGN AND THE EXPERT SYSTEM PROGRAM DESIGN

Sequencing of activities	Before		After		Difference		
	Time (A)	Error points (B)	Time (C)	Error points (E)	A-C=D	B-D=F	D^2
1. Drawing List	1.2	2	1	1	0.2	1	0.04
2. Specification	1.35	2	1	1	0.35	1	0.12
3. Symbol List	1.05	2	0.45	1	0.60	1	0.36
4. Layout Planning	7.53	3	5.2	2	2.33	1	5.42
5. Single Line Diagram	5.38	4	2.13	3	3.25	1	10.56
6. Substation Plan	7.59	3	5.12	2	2.47	1	6.10
7. Main Feeder Design	8	3	6.15	1	1.85	2	3.42
8. Lighting Fixture Design	1.58	1	1.15	1	0.43	0	0.18
9. Lighting System Design	16.45	6	9.53	3	6.92	3	47.88
10. Emergency & Exit Light Design	6.23	3	4.14	2	2.09	1	4.36
11. Receptacle Design	6.41	3	4.3	2	2.11	1	4.45
12. Telephone Design	5.33	2	4.1	1	1.23	1	1.51
13. LAN Design	5.55	2	4.3	1	1.25	1	1.56
14. Fire Alarm Design	10.05	3	6.54	2	3.51	1	12.32
15. Public Address Design	6.3	2	5.11	1	1.19	1	1.41
16. Riser Diagram Design	5.32	3	4	1	1.32	2	1.74
17. Panel Load Schedule Design	6.4	8	3.32	3	3.08	5	9.48
Total	101.72	52	67.54	28	34.18	24	110.9
Average	5.98h.	3.05	3.97 h	1.64	2.01h	1.41	

According to the data in table 1, drawing the bar chart is more understandable to compare percentage of design errors and also time reduction before and after implementation as shown in fig. 8.

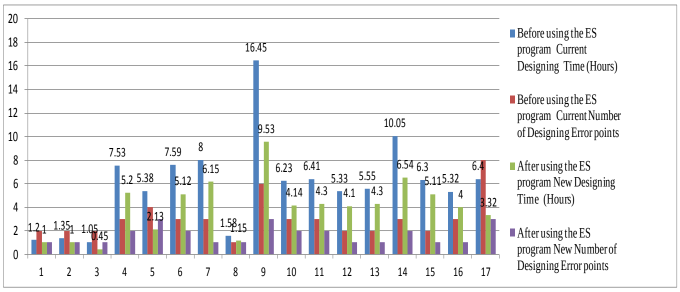

Fig. 8 error percentage comparison of before using the expert system and after using the expert system

In the following procedure, t-stat dependent analysis has been performed [6] using Ms-Excel. The hypothesis is to compare mean between the traditional method before using the expert system (μ_A) and results after using the expert system (μ_B). The analysis result has been depicted as illustrated in equation (4).

$$\text{Hypothesis} \quad H_0: \mu_A = \mu_B \;,\; H_1: \mu_A > \mu_B$$

$$t = \frac{\sum D}{\sqrt{\frac{N\sum D^2 - (\sum D)^2}{N-1}}}, df = N - 1 \qquad (4)$$

$$t = \frac{34.18}{\sqrt{\frac{(17x110.96)-(34.18x34.18)}{17-1}}}, df = 17 - 1 = 16$$

$$t = 34.18/6.69 = 5.10$$

As calculated in equation (4), average current designing time is 5.98 hours and average new designing time is 3.97 hours, with variances 14.07 and 5.53 at 17 observations, t-stat 5.10 > t Critical two-tail 2.1199 ($\alpha = 0.05$), then Reject Hypothesis H_o and accepted H_1. The statistical testing analysis explained that the average time of traditional method (μ_A) is more than after using the expert system (μ_B). Hence, the expert system can improve the capability of time development and design error of industrial factory electricity design.

Furthermore, benefits comparison between current design and new design method in terms of time and cost are presented; before using the ES program project drawing the selling price is worth 500,000 baht. Training time of each project is approximately 5 days with cost 127,150 baht/project. Normal error points are occurred around 52 and training cost 160,000 baht/year with Benefit/Cost (B/C) ration at 1.74. After the implementation of ES program project drawing, the sale is worth the same price. Training time for each project is reduced to only 3 hours with cost 84,425 baht/project. Normal error points are reduced to 28 and training cost as one time investment at 40,000 baht with Benefit/Cost (B/C) ration at 4.02 as illustrated in Table 2.

TABLE II
COMPARISON BETWEEN CURRENT DESIGN AND NEW DESIGN METHOD

Decision Making Criteria	Training Time	Project designing Time	Training Cost	Benefit/cost ratio
Before using the ES program Project drawing sale price 500,000 baht	40 hours or 5 days	101.72 hours Cost = 250 baht/engineer/hour 250*5*101.72 =127,150 baht/project	2000*40 =80,000baht /time Training arrange 2 times/year =160,000 baht/year	500,000/(127,150+160,000) = 500,000/287,150 =1.74 Project margin=212,850 baht
After using the ES program	3 hours	67.54 hours 250*5*67.54 = 84,425 baht/ project	Program development cost =40,000 baht one time	500,000/(84,425+40,000) = 500,000/124,425 4.02 Project margin=375,575 baht
Dif.%	-92.5%	-33.6%	-75%	+76.4%

V. CONCLUSION

This work deploys a comprehensive approach, based on customer needs, to determine main functionalities for electrical layout design of factory. The conclusions from applying this DSS are outlined below,

1. According to data collection of design error before and after using the expert system program to design electrical systems of a case study, we found that average errors of before using the expert system program was equal to 52 points with design period 101.72 hours per project or average around 5.98 hours per activity. After using the expert system program, we could reduce design time to remain 67.54 hours and percentage error down to 46.15% or only 28 points with average design period of only 3.97 hours. It states that the developed DSS can reduce operational errors down to 53.84% or reduce design period to 34.18 hours in this project. In terms of economics, this method can support project cost reduction by reduced training cost and project designing cost with benefit/ cost ratio from traditional method at 1.74 up to 4.02 or project margin is increased 162,725 baht/project.

2. A project planning issue can be improved by using the ability of ES and linkage programs with MS-Excel. This reduces the early design process of an electrical system design, which is more beneficial than transferring information to the other design engineers as a sequential engineering design processes.

3. The problems at the design stage are effectively solved compared with other current methods applying the ES method. The application of such tool provides the key to reduce time development in finding solutions of engineering design.

4. Training time and cost are reduced refer to designed programs and also this tremendously supports new engineers to improve their decision making conveniently at the design stage.

5. The concept of engineering design and safety design based upon electrical facility design can be covered during the conceptual design process because this early integrated methodology has presented the interested law and regulations parameters from a stakeholder's point of view to analyze and assess at the early design phase.

By these reasons, this research can be concluded that this DSS based upon expert system is a way to improve the efficiency in designs of electrical systems for industrial factories and to reduce cost of senior consultants; especially, the lower cost of computer development program using the open source, and the simpler operations by using graphic interface for engineers which can be linked to the design program of nanoCad and can be analysis result exported easily to Ms-Excel. Furthermore, the program can be added-on and data is simply updated to database which can increase the accuracy and completion according to electrical engineering principles, requirements and standards and be improved continuously with better result in the future.

VI. LIMITATION AND RECOMMENDATION

In terms of limitations, the authors experienced difficulties from the experiment that the major cause of wrong designing operations was generated from unstable architecture of customers or contractors. Any revision of electrical system design will be continually impacted the whole systems which generates higher errors such as revised lighting systems impact the load schedule revision, revised electrical loads impact resizing transformers etc. Consequently, for further studies, if the expert system program of electrical systems for industrial factories is able to be revised for any point per requirements of customers, it can promptly eliminate continuous impacts in systems. Nevertheless, the program can display results in 3D modeling when it is co-operated with other programs such as co-operations among BIM (building information modeling), architectural, structural, Electrical, Mechanical programs, etc. in order to enhance the expert system program with greater efficiency.

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