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Economic Investigation of High Quality Thermal Inspections

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This paper investigates the economics of thermal inspections of electrical equipments using a Matlab Graphic User Interface "GUI" with thermal imaging infrared "IR" camera. In spite of the benefits of thermal inspections, its actual utilization with traditional procedures necessitates relying on external inspection experts. This increases the cost of inspection resulting in unbeneficial commercial process. The proposed technique provides an effective method to predict and solve abnormal conditions in electrical equipments avoiding the need for external inspection experts. Thus, all electrical equipments can be tested with an economic manner, where the overall cost can be significantly reduced. The paper highlights also the benefits of the proposed technique in providing a complete thermal profile of the system to define the particular condition or fault corresponding to the thermal signature. The performed report defines the problems that found in the system, suggests remedy and performs any necessary corrective action in a suitable time and recommends for the priority of correcting these problems. Accordingly, the economic aspects of thermal imaging IR cameras will take new forms, which will enable their actual utilization in large scales.

Keywords: Economic operation, Graphic user interface, Predictive maintenance, Thermal inspection.

1. Introduction

One of the main tasks of safety representatives is to carry out inspections, especially for important and essential equipments. Inspection processes are vital in the operation of power systems due to the need for safe and continuous operation [1]. Conventionally, a highly-experienced representative is required in the analysis process to recommend for suitable solutions. The problems of the predictive inspections in the actual utilization include the increased investment in staff training and ignoring the economical benefits of this process by the management. In addition, there is a problem regarding high investment of purchasing inspection hardware and software, upgrading and calibrating software, setting up a predictive maintenance database, and developing the final report. These problems may discourage the use of such methods [2]. The economic analysis can easily indicate that the possible damage cost is not far away from the expense of the thermal inspections in some cases such as small projects. Hence, the thermal inspection is not recommended in these projects especially when the owner has no confidence on the feasibility of this process.

With modern techniques and software, it is possible to avoid the need for highly-experienced representative to analyze the inspection and extract suitable recommendations. It is required to provide an interface between the infrared “IR” camera and the operator that facilitates the analysis process. In this case, a major part of the inspection cost will be eliminated, which encourages the use of this method in large scales [3], [4]. However, high accuracy has to be provided by the interface scheme to guarantee accurate inspection.

A computerized maintenance management system “CMMS” is introduced in [5], where its implementation cost varies depending on the selected solution. The costs in this case can

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reach $100,000, which represents a high and unacceptable cost for most projects. The utilization of the IR camera costs more than $19,500 without software report possibility. The cost of the IR camera is about $6750 and the training cost is $6,000.The study assumed the training cost only once, while it is essential to consider repetitive trainings for new technicians. In addition, only the basis camera software is used and the improvements of equipments due to regular preventing maintenance during its life did not considered.

The technique for updating sequential predictive maintenance “USPM” policy provided in [6] is a cost-effective manner to decide a real-time predictive maintenance schedule for continuously monitored degrading systems that minimizes maintenance cost rate "MCR" in the long term. However, this method did not consider the unavailability of all information about investigated equipments. Moreover, complex calculation is required to analyze the obtained data, and no software is developed to facilitate the implementation to operators. A system known as infrared thermography anomaly detection algorithm (ITADA) is proposed in [7]. A computerized system is developed depending on artificial intelligence and digital image processing techniques to give automatic decisions. In spite of this, the method did not consider the possibility of poor information about equipments, which depends in most cases on the equipment status based on qualitative way. Similar to the previous cases, no program is used to assist the operator in the decision making. Besides, the results did not consider the serious effect due to the percentage loading. According to [8] and [9], the main decision to define abnormal conditions is based on computational intelligence methods and digital image processing. The diagnosis tool uses a set of neuro-fuzzy networks to generate thermo vision diagnoses by identifying variables related to inspected element and variables affecting decision accuracy. While the research provided high-technology technique, the decision accuracy depends mainly on the number of collected reports. In addition, the technique assigns images that require a lot of money and a large time for analysis.

In this paper, an investigation of the economic aspects related to the thermal inspection is introduced. To emphasise that the problems associated with this trend can be overcome, a proposed technique is presented to facilitate the inspection and analysis of the obtained results. This proposed technique, which is presented in previous researches [3]-[4], provides a management tool that eliminates the need for highly-experienced technician. The objective is to introduce a general framework for the inspection process that can significantly reduce the inspection cost. The analysis ensures the possibility of providing an economic manner to accomplish the inspection with an easy and accurate manner.

2. Problem statement

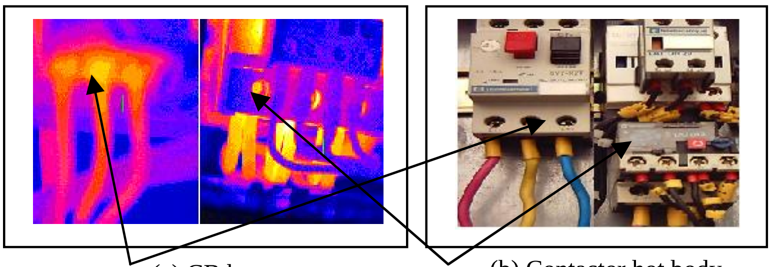
There is a contradictory relation between the predictive inspections, with proper tools and accurate solution reports, and the cost of this process. Thus, it is required to analyze the economic aspects related to this process and to suggest new techniques to facilitate the diagnosis process. Conventionally, IR camera is used as predictive maintenance (PdM) tool to give these targets. However, the expenditure of specialists is normally high enough to discourage realizing this approach. The PdM is usually defined as “measurements that detect the onset of system degradation” [10]. Thus, it is used to define the required maintenance according to the material or equipment status. Through the PdM, the component operation life and availability can be increased and the downtime can be decreased by eliminating breakdowns. In addition, it increases the product quality, improves safety of environment and saves more energy. Thus, PdM can achieve about ten times returning on investment [10]. On the other hand, it has the disadvantages of increasing investment in diagnostic equipments and increasing investment in staff training. In general, any PdM program has to account for the following issues: expected degradation status of equipments, use of suitable databases, modern technology in practice, the history of each equipment starting from its installation and the actual needs of inspection [11].

Predictive inspection requires many tools to be applied such as: vibration monitoring, oil analysis and infrared thermography "IRT". IR technology is non-invasive technique that has many applications such as detection loose connections, corrosion in elements, short circuits, overloaded circuits, and other dangerous faults. In general, this saves both time and money by avoiding untimely machine failures with table of priority [12-14]. In addition, IR technology is absolutely risk-free, easy to use and relatively inexpensive. The idea is to use specialized and highly-sensitive equipment by a skilled technician to identify invisible equipment faults with high accuracy such as overheated electrical switches [15-17]. Also, this technique is applicable in enormous medical and industrial application to give a plan approach to equipment maintenance. IR technology responses to issues before they become critical, reduces downtime due to failure, reduces risk of electrical fire, reduces insurance premiums, and avoids excessive cost normally incurred by corrective maintenance [18-21].

The main problem of using IR camera lies in the analysis of the obtained thermal images. The analysis requires high experience, which increases the cost of the inspection considerably. Without enough experience, the report will not reflect the accurate condition of inspected equipment as illustrated by the following cases:

2.1. Analysis without Enough Experience

In the case shown in Fig. 1 (from author previous work), the primary diagnose indicates that there is an increase in temperature of all three outputs of the circuit breaker "CB". In fact, there is no problem in the CB output connections, but the problem is in the heated contactor beside the CB as shown in the Figure. In other words, the very hot contactor in the right side increases the temperature of the CB in the left side.



(a) CB hot (b) Contactor hot body

Fig. 1 No problem in the CB

2.1. Analysis with enough experience

Sufficient experience will enable the correct inspection and reduces the damage cost. It is clear from Fig. 2 (taken by authors), that there is a very hot output point of the CB, where a rise of 33 °C in one line compared to others is observed. According to the thermal imaging, the report is as follows:

Problem: hot (one of three) point on outlets of moulded case CB, with a temperature rise of 33°C with respect to the other terminals (may lead to a fire in the panel itself)

Remedy: tripping the CB and cleaning this end of cable (may need to cut this end if carbonized) and retightening it good.

Priority: due to temperature rise >20 °C, priority is now

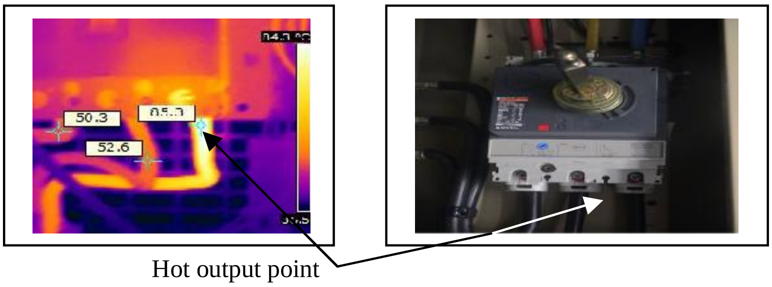


Fig. 2 A problem in the right output line of the CB

Thus, the usefulness of IR analysis can be realized not only as a predictive inspection tool but also as a troubleshooting & engineering tool. From the previous cases, it is clear that the sufficient experience is vital in the analysis of the obtained images. Depending on external experience results in a high inspection cost. With suitable guide software, these costs can be reduced since no high experience will be required. Therefore, it is essential to investigate the economic problem of thermal inspection in two directions. The first is to utilize external experience, which can be termed “conventional analysis”. The second is to develop guide software that substitutes the high experience required in the analysis, which can be termed “internal inspections”. In both cases an economic analysis will be carried out taking into account the corresponding cost of each method.

3. Economic analysis of thermal inspection depending on conventional methods

The conventional analysis, or “external inspections”, depends on delegating outside contractors to accomplish the electrical inspections. The main procedures of inspection are introduced supported by an example for actual implementation of these steps in Egypt (Smart Village, in Cairo-Alexandria fast desert road).

3.1 Collecting data about all inspected equipments in the site

The first step is to collect enough data about all equipments and categorize them in groups according to their type, location…etc. Regarding the Egyptian site as an example, the various inspected equipments have been summarized in Table (1). The cost of all equipments is estimated depending on the average price of the equipment. From Table (1), the capital cost of the inspected equipments is about 18603000 £ (≈$3100500). The percentage cost of each equipment with respect to the total cost is shown in the same table.

3.2. Evaluating the External (Conventional) Inspection Costs

The second step is to evaluate the annual inspection cost, which depends on the number, type and status of equipments. The actual total cost of inspections “V” for the Egyptian site was 30,000 £ (≈ 5000 $). According to the nature and status of the equipments, at least two inspections must be done every year (summer and winter), which results in a total costs of 60,000 £ (≈ 10000$). This cost represents about 0.3225% of the capital cost and hence it forms no matter in the overall investment. However, it will appear as a large value when compared to the running cost.

TABLE 1: Groups of various inspected equipments

Area/Equip.	Transformer	Air conditions	Contactors	MCCB*	MCB**	Control	Motors/ pumps	Cables	Boilers
1		50	100	50	150	10	35	25	2
2		45	90	44	150	8	30	22	2
3		-	100	60	60	15	50	30	-
4		55	100	56	100	8	30	15	1
5	2	-	100	20	10	2	-	20	-
6	2	-	-	18	10	2	-	18	-
7	2	-	-	20	10	2	-	20	-
8	2	-	-	16	8	2	-	16	-
Total No.	8	150	490	284	498	49	145	166	5
Average price/unit (thousand £)	250	2.98	0.5	1500	20	10	44.9	30	700
Total cost (thousand £)	2000	447	245	426	9.96	490	6505	4980	3500
%	10.75	2.4	1.317	2.29	.054	2.634	34.97	26.77	18.82

MCCB* : Moulded Case CB MCB** : Miniature CB

3.3. Introducing the effect of depreciations on inspection costs

The depreciation of equipment increases the required inspections and thus, increases the inspection cost. Assuming that the value of equipment at starting installation is “P”, the equipment lifetime is “N”, the salvage value is “S” and the depreciation each year is “A”, the straight line method in [22] can be used as follows:

$$A = (P-S) / N \quad (1)$$

Applying this criterion on the Egyptian site, the value of “A” can be decided by supposing the followings: P = 100% (capital cost), N = 20 years (life of equipment "assume") and S = 30% (at the end of 20 years). Thus, the value of “A” can be obtained from equation (1) to be A = 3.5%. Assuming that, the annual percentage increase of the inspection cost is the same as the annual percentage of depreciation of the equipment “A”, thus, the increase of inspection cost is:

$$B = A*V/100 \quad (2)$$

Thus, the inspection cost can be calculated every year as:

1- First year inspection cost = V (0.3225% with respect to P)
2- The inspection cost increase in each year (B) is: B= A*V=0.01128% (with respect to P)
3- Second year inspection cost = V+B*V = 0.3337% (with respect to P)

At the N^{th} year, cost = $V (1+B)^{N-1}$ (3)

After 20 year, inspection cost will be: $0.3225 (1+0.01128)^{19} = 0.39916\%$ (with respect to P)

After calculating inspection costs at the end of each year, inspection costs will be accumulated as shown in the Table (2).

3.4. Taking the extension in equipment lifetime into account

According to [23] and [24], the life of equipment is significantly reduced with the temperature rise. Thus, the equipment life can be extended with the predictive inspections.

The extension in equipment life is assumed to vary between 5 to 20% of the lifetime without inspection. Thus, the expected average lifetime of equipments will be as follows:

1- 21 years for 5% extension, where the corresponding value of “A” is: 3.333%
2- 22 years for 10% extension, where the corresponding value of “A” is: 3.1818%
3- 23 years for 15% extension, where the corresponding value of “A” is: 3.04347%
4- 24 years for 20% extension, where the corresponding value of “A” is: 2.91666%

TABLE 2: Relationship between depreciation and accompanied accumulations of external inspections

Years	Value of equip. with 5-20% and without extension life				External inspections cost (accumulation) with (5-20%) and without (0%) extension life of equipments						
	0%	5%	…	20%	0%	Acc.	5%	Acc.	…	20%	Acc.
0	100	100	…	100	0	0	0	0	…	0	0
1	96.5	96.7	…	97.1	0.323	0.32	0.323	0.32	…	0.323	0.32
2	93	93.3	…	94.2	0.326	0.65	0.326	0.65	…	0.326	0.65
3	89.5	90	…	91.3	0.33	0.98	0.329	0.98	…	0.329	0.98
4	86	86.7	…	88.3	0.333	1.31	0.333	1.31	…	0.332	1.31
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
9	68.5	70	…	73.8	0.353	3.04	0.351	3.03	…	0.348	3.01
10	65	66.7	…	70.8	0.357	3.39	0.355	3.39	…	0.351	3.37
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Taking these extensions of equipment life into account, the percentage change in inspections will be: 0.01128% for 20 years, 0.010748% for 21 years, 0.01026% for 22 years, 0.009815% for 23 years and 0.009406% for 24 years. From the above discussion, the calculations can be repeated as given in Table (2), which gives the relationship between the depreciation and accompanied accumulations of external inspections.

3.5. Analyzing the net inspection cost according to saving in depreciation

As shown in Table (2), there is a rise in the equipment salvage value ”S“ with extension of equipment lifetime. For example, the equipment values at the end of the 10th year equal 65%, 66.66%, 68.18%, 69.57% and 70.83% with extensions in the lifetime of 0%, 5%, 10%, 15% and 20% respectively. In other words, there is an increase in the salvage value “S” of: 1.66%, 3.18%, 4.57% and 5.83% for extensions in the lifetime of 0%, 5%, 10%, 15% and 20% respectively. On the other hand, the total (accumulations) inspection costs at the same year (10th year) equal 3.392%, 3.3839%, 3.3759%, 3.3707% and 3.36477% for extensions in the lifetime of 0%, 5%, 10%, 15% and 20% respectively.

It can be concluded that the difference between the saving in depreciations and the accumulation inspection costs varies depending on the extensions in the lifetime, where it can be negative (paying money) or positive (saving money) as indicated by the net difference. The net difference for 0%, 5%, 10%, 15% and 20% extension in the lifetime at the end of the 10th year are respectively: -3.392% (paid), -1.7239% (paid), -0.1959% (paid), + 1.1993% (saved) and +2.46523% (saved). Tables 3 and 4 summarize the previous calculations for different extensions in equipment life at different years.

The tables indicate that the inspection process can cause a net saving due to the resultant extension in the equipment lifetime. For instance, the total inspection cost at the end of the 20th year is about 7.1838% neglecting the extension of lifetime. On the other hand, if the decreasing in the depreciation value is taken into account, the total cost of inspections decreases by significant values from paying money of 7.1838% to saving money of 4.601%. With different extensions in equipment lifetime (N), new tables similar to Tables (2), (3) and (4) can be derived, to show the benefits of predictive inspections. Such values can be summarized by the following charts shown in Figures 3, 4 and 5.

TABLE 3: Differences between savings in depreciations and external inspections values

Extension in equip. life	Differences as a net saving for extension in equipment life from 0% to 20% depreciations				Accumulation costs of external inspections for various cases of extension in the lifetime (0%-20%) with respect to P			
Years	0-5%	0-10%	0-15%	0-20%	0%	5%	…	20%
0	0	0	0	0	0	0	…	0
1	0.16	0.318	0.45	0.58	0.3225	0.3225	…	0.3225
2	0.33	0.637	0.914	1.166	0.648	0.6484	…	0.64803
3	0.5	0.955	1.37	1.749	0.9783	0.9778	…	0.97662
4	0.66	1.273	1.828	2.333	1.3117	1.3107	…	1.3083
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
9	1.5	2.8636	4.113	5.249	3.0355	3.029	…	3.01394
10	1.66	3.18	4.57	5.83	3.392	3.3839	…	3.36477
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

TABLE 4: Net cost of external inspection after subtracting the depreciation values

Years \ Extension of equip. life	0%	5%	10%	15%	20%
0	0	0	0	0	0
1	-0.3225	-0.1625	-0.0045	0.1275	0.2575
2	-0.648	-0.3184	-0.0114	0.26584	0.51797
3	-0.9783	-0.4778	-0.0226	0.39304	0.77238
4	-1.3117	-0.6507	-0.037	0.5191	1.0247
⋮	⋮	⋮	⋮	⋮	⋮
9	-3.0355	-1.529	-0.1584	1.0944	2.23506
10	-3.392	-1.7239	-0.1959	1.1993	2.46523
⋮	⋮	⋮	⋮	⋮	⋮

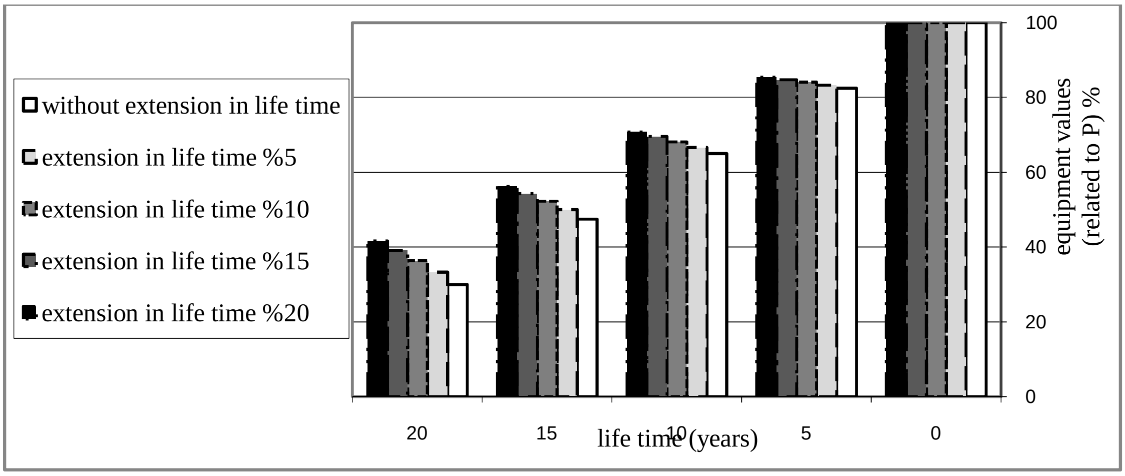


Fig. 3 Increase of Equipment values due to inspection at different equipment lifetime

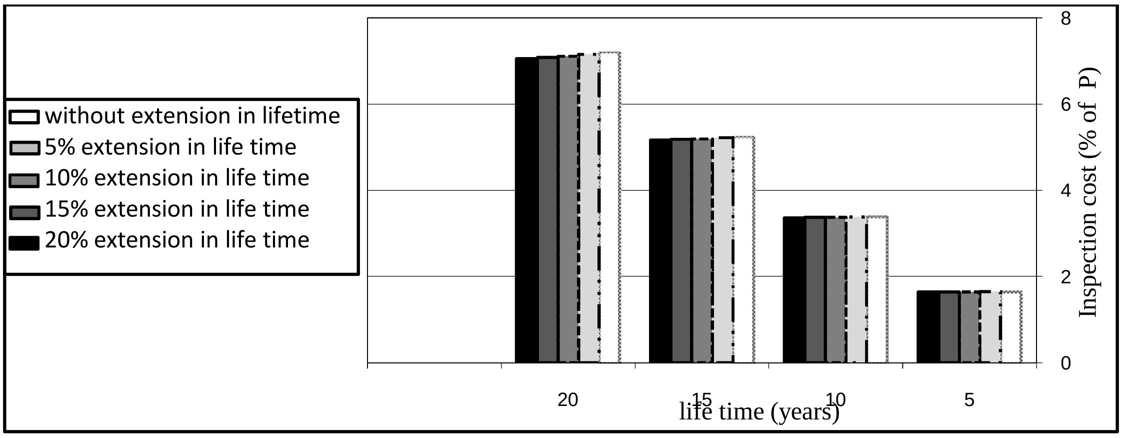


Fig. 4 Inspection costs during equipment lifetime: External inspection

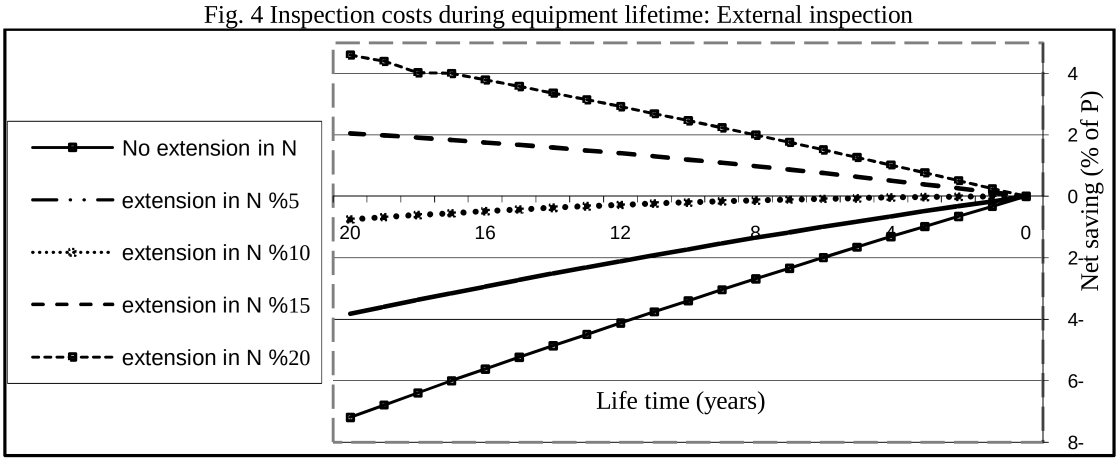


Fig. 5 Net Saving (Return due to extended lifetime - External accumulated inspection costs)

4. Economic analysis depending on the proposed inspection method

The proposed technique "internal inspections" is a cost-effective method that can provide many benefits over the external thermal inspection. The inspection and its reports will be developed by a technician or any engineer in the site. The detailed descriptions of the proposed analysis policy, as well as its underlying assumptions are given as follows:

- Purchasing a suitable IR camera with appropriate application capabilities (applied for electromechanical equipments, moderate ranges of temperatures and length…etc.). The price of such IR camera ranges from 8000 to 12000$. Thus, it is assumed that the IR camera will operate for 10 years with full efficiency with an average price of 10000$.
- According to the estimated equipment life, N = 20 years, two IR cameras will be required with a total cost of 20,000$.
- A certain amount has to be appointed, as will be shown later, to the calibration process for the IR cameras each year.
- The inspection-program cost for the proposed analysis technique, which uses Graphical User Interface" GUI" aided by a Matlab programs, has to be identified. The expected price of the program, depending on the self experience and the program developed by the authors, may be 2500$ (for inspection of electrical equipment).

4.1. Methodology

By using a GUI Matlab program containing a database about all data of various electrical equipments in the site, it will be easy for any engineer or operator to accomplish the full inspection process. The operator should have only basis information about site equipments. Thus, it will be possible with the proposed techniques “thermal analysis inspections” aided by IR camera to obtain accurate reports for different electrical equipments problems. Figure (6) shows the interface window of the program to clarify the idea of this methodology. This program can assist the operator to select his case study with easy manner. There are some steps, which the operator must be follow to produce accurate report. A detailed description of the methodology is introduced in a previous work [3].

4.2. Calculation of Internal Inspections Costs

Based on the methodology introduced in the previous section, the total cost of the proposed inspection technique can be calculated as follows:

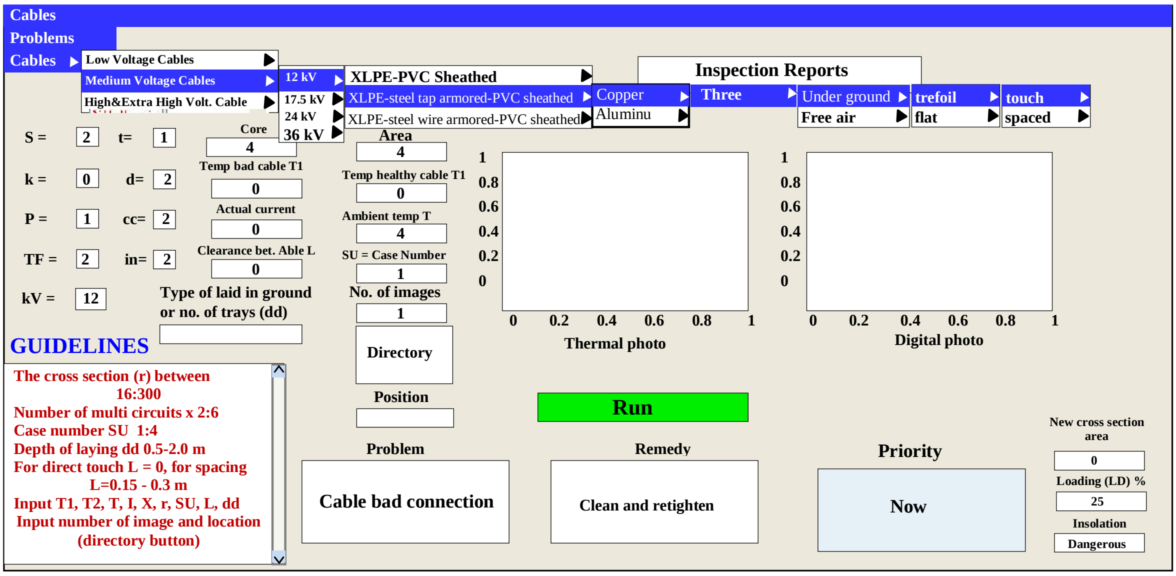


Fig. 6 The interface window of the program methodology

1- The total cost of the IR cameras and the proposed analysis programs are calculated for the whole lifetime of equipments. This cost is about 22,500 $ for 20 years,
2- The annual cost is then derived: Cost of each year =22500/20= 1125 $/year,
3- Then, the annual internal inspections cost with respect to capital cost (P) is calculated as: 1125/3100500*100=0.03628%. Thus, the internal inspections cost is about 11.25% of the external inspection cost and a saving of 0.2862% of capital cost can be achieved.
4- The effect of calibration cost is introduced and the total cost for 20 year is obtained as:
   a- The cost of the first year is taken without modifications: V = 0.036284%
   b- A certain value is suggested for the calibration cost of IR camera ”X” with a yearly percentage increase. In this study, ”X” is taken as 10% of ”V”, with 10% increase of this values each year.
   c- Based on steps “a” and “b”, the cost of all years through the lifetime can be calculated as follows:
      1) First year = V,
      2) Second years = V+ X = 1.1 V,

3) Third years = V+X +0.1X = V+1.1X =1.11V, and so on other years;

For the 20th year, the cost is 1.555V

Similar to the analysis for the external inspection, the previous calculations are summarized in Tables 5 and 6 with its accumulations with respect to depreciations.

TABLE 5: Differences between savings in depreciations and total internal inspections

extension equip. life	Differences as a net saving for extension in equipment life between 0% and 20% depreciations				Accumulation costs of internal inspections for various cases of extension in the lifetime (0%-20%) w.r.t capital cost (%)	
Years	0-5%	0-10%	0-15%	0-20%	Cost	accumulation
0	0	0	0	0	0	0
1	0.16	0.318	0.45	0.58	0.036284	0.03628
2	0.33	0.637	0.914	1.166	0.03991	0.07618
3	0.5	0.955	1.37	1.749	0.04027	0.011645
⋮	⋮	⋮	⋮	⋮	⋮	⋮
10	1.66	3.18	4.57	5.83	0.04404	0.412284
11	1.83	3.499	5.027	6.416	0.04483	0.457114
⋮	⋮	⋮	⋮	⋮	⋮	⋮
19	3.16	6.043	8.683	11.082	0.0546	0.8548
20	3.33	6.3616	9.14	11.66	0.056437	0.91124

TABLE 6: Net cost of internal inspection after subtracting the depreciation values

extended equip. life / Years	0%	5%	10%	15%	20%
0	0	0	0	0	0
1	-0.03628	0.12372	0.28172	0.41372	0.54372
2	-0.07618	0.25382	0.56082	0.83782	1.08982
3	-0.01165	0.38355	0.83855	1.25355	1.63255
4	-0.15705	0.50295	1.11595	1.6709	2.1759
⋮	⋮	⋮	⋮	⋮	⋮
9	-0.36788	1.13212	2.49572	3.74512	4.88112
10	-0.41228	1.24772	2.7677	4.15772	5.41772
…	…	…	…	…	…

It can be concluded that internal inspection can reduce the inspection cost considerably. At the end of the 10th year, the net cost equals 0.412284% resulting in a saving of 2.9797% compared to external inspections for 0% extension lifetime. Taking into account the extension in equipments lifetime caused by predictive inspections, the proposed inspections technique achieves a considerable saving as shown in Table 6. At the end of the 10th year for example, the paying is about 0.412284% for 0% extension in lifetime, while the saving is about 5.417716% for 20% extension in lifetime. The previous calculations can be applied for different values of equipment life (N), salvage values (S) and extensions of lifetime (N) (0%, 5% ...etc.) and the results are illustrated in Figure 7.

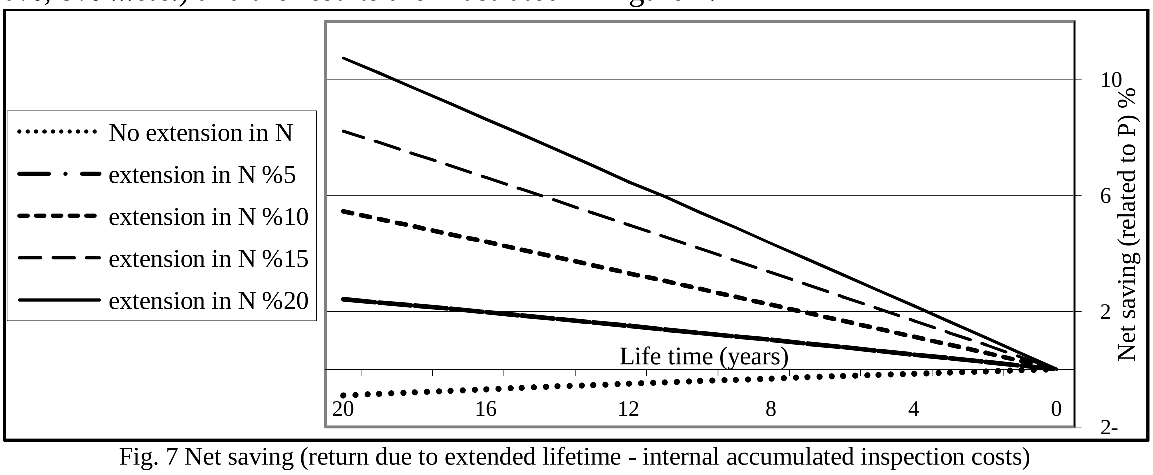


Fig. 7 Net saving (return due to extended lifetime - internal accumulated inspection costs)

4.3. Breakpoints for utilizing predictive inspections

This section provides a general framework to enable higher management to decide for utilizing predictive inspections. The evaluation is based on the proposed technique and taken 15% extension in equipment lifetime as an example as follows:

- At the end of 20 years, the savings due to extension in operating life from 0% to 15% is 9.14% (relate to capital cost P) as shown in Figure 7.
- Equating this value of saving, 9.14%, with total internal inspections costs, which are 28253 $, the inspection cost will be completely compensated through the saving due to extension of equipment life. The equipment capital costs are calculated from the relation: 28253/9.14*100, which equal 309113.78 $.
- According to the linear relation shown in Figure 7, the net payment (inspection costs-saving due to extension of equipment life) will vary according to the following equation:

Net saving =9.14-28253/P*100 (4)

Where: "P" is the capital equipment costs ($). The net payment may be negative (paying money) or positive (saving money). Applying equation (4) for all saving values ranging from 5 to 20% aided by Table 6, the equations to define the economic situation are given as follows:

For 5% extension : → Net saving =3.33 - 28253/P*100 (5)

For 10% extension: → Net saving=6.3616 - 28253/P*100 (6)

For 15% extension: → Net saving=9.14 - 28253/P*100 (7)

For 20% extension: → Net saving= 11.66 - 28253/P*100 (8)

Using equations 4 through 8, it is possible to select the economic points (break points) in various cases. Table (7) can be derived from these equations to illustrate economic points of internal inspection costs (%). The idea is illustrated in a chart form in Figure 8.

TABLE 7: Economic situation of internal inspection costs (%) related to capital cost

extended equip. life / Capital cost $	5%	10%	15%	20%
100,000	-24.923	-21.8914	-19.113	-16.593
200,000	-10.7965	-7.765	-4.9865	-2.4665
300,000	-6.0876	-3.056	-0.2776	2.2423
400,000	-3.733	-0.7016	2.0767	4.5967
…	…	…	…	…

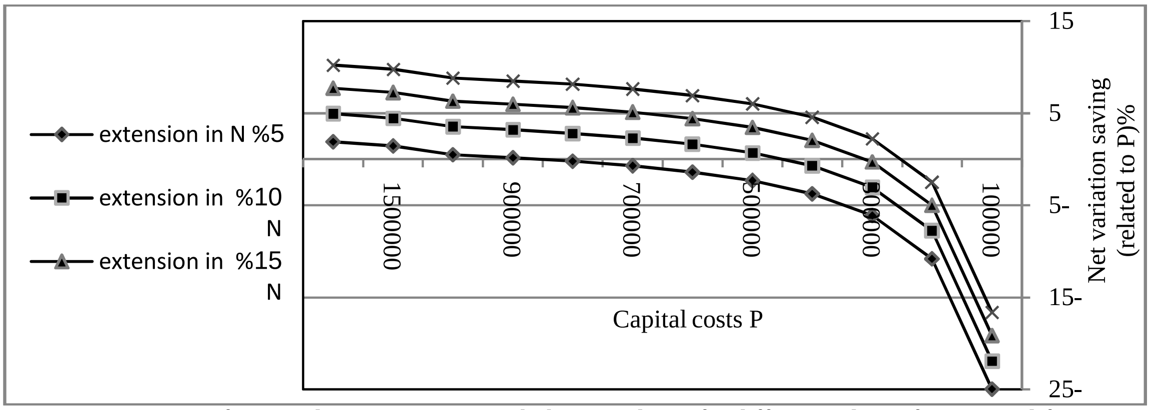


Fig. 8 Variation of saving due to inspection with the capital cost for different values of extension lifetime

5. Discussion and Conclusion

The obtained results and analysis ensured the possibility of carrying out the inspection process in an economic manner. The inspection cost depending on external inspection may represent a considerable cost regarding the running cost. Therefore, a proposed technique is introduced to facilitate the internal predictive inspections to reduce the process cost and enable the secure operation of electrical equipments. The analysis proved that the proposed internal inspection can provide many advantages over the conventional external inspection. Internal inspections cause insignificant cost with respect to the total capital cost of equipment. For 20 years operating life, the total internal inspection cost is about 0.91124% of the capital cost, saving about 6.27256% regarding the external inspections omitting the extension in the operating life due to the PdM. Taking the extension in equipment life into account, the total cost of inspections can be compensated resulting in a net saving, e.g. instead of paying about 0.91124% of the fixed cost, 10.74876% of the fixed cost is earned assuming 20% extension in the equipment life.

The percentage cost of predictive inspection decreases with the increase of the capital cost of equipment. The extension of equipment life due to the predictive inspection has to be accurately estimated by experts since it affects the evaluation of the effectiveness of PdM significantly. Wrong estimation of this extension in equipment life can be misleading and can cause incorrect decisions. In addition to the economic benefits of the internal inspection, it is also advantageous since it can reduce the time required to prepare the report of the problem(s) since it avoids the time requested by the experienced personnel to complete the evaluation and recommend for the solutions. Briefly, the proposed internal inspection technique can provide economic as well as technical advantages that encourage the wide utilization of PdM.

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