MAINTENANCE PROCESS FOR TRANSMISSION TOWERS

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ABSTRACT

In this study, maintenance process for transmission towers were determined based on the investigated results from surveying of the existing towers and by collecting maintenance data from the Electricity Generating Authority of Thailand (EGAT). The field areas were divided to industrial area, city area, rural I area and rural II area in order to determine the characteristics and causes of the tower damage. The data from fields surveying were used to determine the relationship between rust level and age of tower.

Results of the study showed that rust of the tower tend to mostly occur in the industrial area. Severe corrosion was found at the stubs. Step-bolts, ladders and member joints were also found to be more corrosive than other members. Some tower foundations had high settlement. Furthermore, some members in the lower part of the tower were deformed or lost. The location, environment, topography, climate, construction process, transportation method, unsuitable storage and human act for examples could cause the damages.

This research offers the protective and maintained means of the tower. It setups the process for maintenance by divided to basic and elaborating investigation. This could extend the lifetime of the towers and can be used to develop the standard for tower design in the future.

Keywords: Maintenance Process / Damage of Transmission Towers / Causes of Damage / Grade of Corrosion / Transmission Tower

1. Introduction

Electricity is an important basic factor for developing countries. Electricity, which is generated from important sources of country, will be transferred to minor electrical station spreading through out the country via high voltage Transmission towers. The towers normally used in Thailand were made of many pieces of galvanized steel bars. The steel is not stable when used in natural environment. It has tendency to deteriorate and damage from many factors. Some environments and atmospheres are the other factors that affecting corrosion (Chotimongkol 1999, Hue 1999 and Lien 1999). Researches in the past concerned about corrosion behavior of steel (Rungthongbaisuree 1995) and corrosion behavior of 24 existing in the steel structures factories in Thailand (Rungthongbaisuree 1998) and also steel structures in 5 oil refineries in Thailand (Rungthongbaisuree 1999).

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Although the researches on the corrosive behavior of steel structures have been significantly done, the systems of examination and maintenance for Transmission towers have not been sufficiently developed. In Japan, the study on systems for checking the deterioration on painting of transmission towers has been done (Yamakata 1990). For this study, by employing all of the data, the systems for checking the transmission tower can be established. As the results, the guidelines for developing the standards of maintaining transmission tower can be made and that also can increase the operating time of towers.

2. Investigation Process

Investigation process was divided into 2 parts as follows:

2.1 Site survey in 4 areas of different environments. There are

a. Industrial area :
Sub Bangkoknoi – Sub South Thonburi –Sub South Bangkok – Sub Bangphli, Bangkok

b. City area :
Sub Bangkapi – Sub Onnuch – Sub Bangphli, Bangkok

c. Rural I area :
Sub Bangphli – Sub Bangpakong and Sub Onnuch – Sub Bangpakong, Samutprakarn

d. Rural II area :
Sub Banglamung – Sub Chomthien – Sub Satthahip I – Sub Satthahip II, Chonburi

Table 1: Average meteorological characteristics for observed areas during total period of study (1971-2000)

Investigated Areas	Temp. (°C)	RH (%)	Evap. (mm.)	SD (hr.)	Wind (Knots)	Rainfall (mm.)
Industrial	28.4	73	1860	2358	-	1466
City	28.2	75	1783	2454	45	1543
Rural I	27.9	71	1809	2352	-	1294
Rural II	27.7	77	1801	2273	99	1124

Remark :

1. Temperature: The average temperature of each zone; unit: degree Celsius.
2. Relative Humidity: The average relative humidity in each zone that is expressed as percent of humidity.

3. Evaporation: The annual average of water content evaporation in each zone and it is measured by a checking pan; unit: mm.
4. Sunshine Duration: The annual average of total duration that the sunshine comes through each zone; unit: hour.
5. Maximum Wind Speed: The maximum wind speed in each zone during 1971 – 2000; unit: knots. (1 knot = 1.853 km/h)
6. Rainfall: The average of content of rainfall in each zone per year; unit: mm.

It was specified to be at least 30 towers in each area for sample collection. Entire structure and each component of the towers were visual inspected for corrosion deterioration and damage. Including the consideration on the surrounding environments.

2.2 Collection of maintenance records and other data from EGAT.

3. Results of the Examination

This section is separated into 3 parts:

3.1 Local Prevention and Maintenance of the Damage of Transmission Tower

By collecting the data, it is found that the types of deterioration and damage of transmission tower are varied. This study has analyze for the causes of such that problems and then propose the guideline for the maintenance and prevention.

1. Types of Deterioration and Damage of the Transmission Towers:
   - *a.* Rust covering on the entire structure of transmission tower
   - *b.* Severe corrosion at the joint between the end of leg members and the base of towers
   - *c.* Rust covering on the joint connections
   - *d.* Rust covering and corrosion on the step-bolts and ladders
   - *e.* Deformation and loss of the structure members
   - *f.* Settlement of foundation
   - *g.* Abnormally rust covering on some of the structure members
2. Causes of Damage and factors effecting the degree of deterioration of transmission Towers:
   - *a.* Operation period
   - *b.* Landscape and location
   - *c.* Climatic of Thailand
   - *d.* Difference on the standards of galvanizing
   - *e.* Unsuitability on the construction methods, transportation and material stock
   - *f.* Fluctuation of surface water at the bottom end of leg members
   - *g.* High moisture content at joint connections
   - *h.* High moisture content over the area on which the weed or materials cover
   - *i.* Settlement of the construction site
   - *j.* Differential settlement of leg members
   - *k.* Collision against the structures by vehicles or agricultural machines running nearby
   - *l.* Stealing the structure members
   - *m.* Excavation near the structures of transmission tower

3. Maintenance of Transmission Towers:
    a. Always investigate and check the transmission tower
    b. Plan efficient examination process
    c. Remove rust and make re-coating when highly corroded area was found
    d. Drainage flood so quickly from tower base or change the way of water
    e. Cover concrete at the leg of tower higher than the highest water level after draining flood
    f. Remove covering of weed, earth fill and other material from the tower base
    g. Check the level of tower base when it was abnormally
    h. Repair or replace the members in the case of highly damaged
    i. Replace the member that was stolen
    j. Reinforce the earth i.e. grouting
4. Prevention of Damage on Transmission Towers:
    a. Design suitable coating, materials and protection method with environment in each area
    b. Design good foundation in order to prevent settlement
    c. Plan the good right of way
    d. Avoid locate the Transmission towers in the pond area
    e. Selection suitable and standard materials
    f. Proper transportation and storing method as well as construction procedure
    g. During installation, nuts and bolts should be cleaned especially at the connecting ends
    h. Cover the leg of towers with concrete higher than highest water level
    i. Establish method for water drainage that wastewater could not flow through the towers
    j. Not allow planting at the right of way
    k. Not allow vehicles or agricultural machines work near the right of way
    l. Not allow piling up earth fill and covering weed and other materials at the tower base
    m. Install warning board to inform people about danger of robbed or tower member damage

3.2 System for Investigating the Deterioration of Transmission Tower due to Corrosion

According to the data of rusting investigation in each area, the generation of rust can be classified to 4 levels as follow:

1. A-Level (more than 40 percent of rust covered over the steel surface.) : Re-painting is needed.
2. B-Level (30 – 40 percent of rust covered.): Partially rust covered. Towers must be re-painted by simultaneously considering on the investigating data.
3. C-Level (20 – 30 percent of rust covered.) : Start generating of rust. Towers should be investigated for rust and also re-painted in case they are needed.

4. D-Level (lower than 20 percent of rust covered) : The tower structures remain their origins.

Due to the data of investigating on corrosion, the relationship between the level of rust covering and age of tower for each area can be expressed as shown on Figure 1.

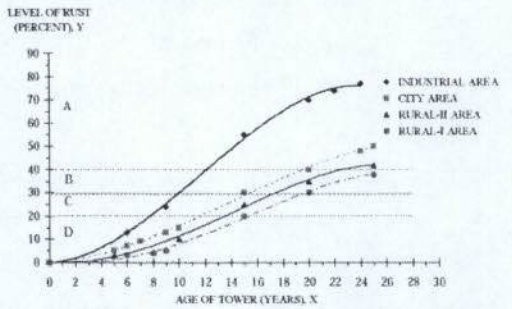

Fig. 1 Relationship between the level of rust covering and age of tower for each area

The aforementioned relationship can be expressed in the form of graph. The X-axis and Y-axis represent age of tower in term of year and level of rust covering in term of percent respectively. By the method of least square the relationship above for each area can be expressed as follows:

1. Industrial Area : $Y=-0.011X^3+0.3862X^2+0.2187X-0.0883$; $R^2 = 0.9987$
2. City Area : $Y = -0.004X^3+01689X^2+0.2869X-0.0591$; $R^2 = 0.9989$
3. Rural-I Area : $Y = -0.00009X^4-0.0004X^3+0.1451X^2-0.5453X+0.1099$; $R^2 = 0.997$
4. Rural-II Area : $Y = -0.00007X^4-0.0021X^3+0.1772X^2-0.3765X+0.127$; $R^2 = 0.9973$

From fig. 1, the percentage of corrosion is descending arranged to be the industrial, city, rural-II and rural-I area. The highest percentage of corrosion in industrial area is the effect of air pollution, which mainly is acid or gas released from the factories. The air pollution will be the cause of rapid corrosion on tower structures. For the city area, the corrosion is the results of wastewater from community and air pollution from the traffic. Nonetheless, the air pollution do not strongly affect on the structures in rural-II and rural-I. For the rural-II, the effect of saline evaporation will be remained because of not far from the seashore.

Figure 1 can be used to quantify the level of rust covering by reading the information from the line, perpendicular to X-axis, starting at a specific time on the axis and intersect with the graph on the classified area. For example, the level of rust covering at thirteen years for the industrial, city, rural-I and rural-II area will be A-, C-, D- and D- level, respectively.

3.3 System for Totally Investigating the Deterioration and Damage of Transmission Towers

Combining the methods in part I and II, the system for totally investigating the deterioration and damage of Transmission towers can be done by dividing the investigation into 2 types:

1. Basic Investigation

This method is quite economic but cover on a large area and can examine rapidly. The period of investigation is depended on the environment, landscape and the position of transmission towers. The basic investigation is classified to 3 types:

a) Monthly Investigation

This must be done on the areas that tend to be more damaged. The samples of checklist are shown below.

- Area that is full of plants along with the right of way. They must be cut off to prevent the flashover and short-circuit according to the regulations.
- Area in which the agricultural machines are working nearby or excavation along with the right of way. The machines will cause the damages of tower by pushing against the structures or collapsing the base of tower due to the excavation.
- Area that usually risks to the effects of wind. The tower may be turned over and that causes the damage of tower. The urgent investigation is necessary.
- Area in which the thieves are. The members of structure may be released or stolen. The investigation of tower must be done more and the organization should point out people to the dangers of unstable structures.

b) Quarter-Year Investigation

The method can be employed to general purposed areas that do not have more risk factors. The period is quite suitable for both the cost of investigation and the duration of periodically checking the structures.

- Area that is full of weed along with the right of way. They must be cut off or sprayed out according to the regulations.
- Area that leg members of tower contact to the wastewater, for example, towers near the huge of rubbish. The corrosion of the leg members due to the acidity of the contacting water must be observed. Taking the pictures and recording the data of this problem may be needed for finding out the solutions.

c) Half-Year Investigation

The method is used for the area in which the towers hardly risk to the damage factors or the towers are gradually damaged and do not need the instant repairing.

- Area that is soft and always flood. The differential settlement of leg members can be occurred. Thus the levels of leg member each must be measured and then compared to each other.
- Area that is such like a pond or farm. The level of water is always fluctuated and that causes the corrosion of tower structures or differential settlement of leg members. The investigation is also needed.

2. Elaborating Investigation

This must be done as planned. It also takes a long time and employs many labors for examination. Besides that, the report papers of transmission line are needed and the transmission line investigation by helicopter is sometimes simultaneously operated. The periods of investigation, as explained in part II, are obtained from the statistical data that is consequently expressed in form of the relationship between the level of rust covering and age of tower for each area.

From the above information, the operation system for the elaborating investigation has been begun from the checking cycle at the 8 or 12 or 14 or 15 year for industrial area, city area, rural-II area and rural-I area respectively that is started from the first use of tower or the last complete repairing.

In case the repairing completes, a new cycle is applied. Nonetheless, in case the operations of repairing are ignored or partially completed due to a small damage and lack of budget, the second cycle of investigation is done at the next 2 or 4 or 3 or 5 year. The variation of checking interval is depended . on the zone that the first inspection is set. After finishing the repairing processes of the second inspection, the inspection can get into the new cycle. However, if the processes cannot be completed, the third inspection has to be set at the next 4, 8, 8 or 10 year from the first inspection. At this cycle, the operations of repairing must be definitely accomplished before going into the new cycle of inspection.

General Inspection List

This list is used generally for checking the deterioration and damage of transmission tower. The same inspection list is also employed for all investigating area so as to thoroughly govern all problems. For each of the exploration, the details on checking list must be recorded in order to find the solutions of such that problems and also employed as the database for analyzing the problems of deterioration and damage of transmission tower. The lists of general inspection can be presented as follows:

a) Inspect for rust covering at members of tower structure

Checking the members for appearing and also quantifying of rust. In case the abnormality, some members are more rust cover than the others, occurs, the record must be made to analyze the problems.

b) Inspect the entire tower structure

Checking the entire members for the faults of bending and their positions. The records and photographs must be done. Moreover, checking for the loss of important members such as bolts, nuts and step bolts is also necessary.

c) Inspect the behaviors in the area of stub

Checking the behavior at the connection between leg members and base. This area is highly risk to be damaged due to many effects, large settlement of foundation leading the stubs to be elongated, back-filling at the bottom of towers, fluctuation of water level and also severely corrosion from wastewater. The analysis for rapidly preparing the corrective actions must be made by employing the data from the records and photographs.

d) Inspect for the corrosion of joint connections

Since at the points of joint connection compose of bolts, nuts, plates and end of members which all are easily covered by rust, these points are highly risk to be corrosive.

e) Inspect for abrasion and corrosion of step bolts and ladders

The step bolts and ladders are all always abrasive due to their operations. These structures thus can be damaged. Besides that, the accumulation of vapors and precipitation, cause of high moisture, can lead to generating the rust.

f) Inspect the foundation

The foundation is an important structure of transmission tower and it is also highly risk to be damaged due to the surrounding effects, soft soil, excavation and operation of machines near the base of tower or under the right of way and that causes the differential settlement. Comparing the level of each leg members by leveling machine is needed to instantly take some actions in case the differences of level are significant.

g) Inspect the surrounding area and right of way

Not only is the tower structure that should be inspected but the surrounding areas must be checked. The surrounding areas, which affect the tower structures, are characterized as follow :

- The trees, which are cut off or pulled out and lean to the tower, in the right of way may cause the damages.
- The plenty of weed surrounding the bottom of tower can highly keep the moisture and that causes the rust.
- The excavation for reservoirs or channels might cause the large settlement of foundation.
- The machines operating for agricultural activities may collide to the towers and cause the structures deformed.
- The towers in the area in which a lot of birds live may be damaged due to the waste of such birds.

Also the records and photographs of inspection are necessary.

h) Totally inspect for entire structure

This is to totally check for the damages of tower structure including its accessories, which are tower number, phasing sign, aerial patrol sign or danger sign. The loss and deformation of such equipment must be examined including the covering of rust. The transmission caps may be checked for being break down. At the high elevation that some members are out of sight, the binocular can be used.

Note : For some details of basic investigation also can be applied to elaborating investigation for establish some actions. Nonetheless, for some specific areas, some details of inspection may be neglected, towers in reservoir may not check for deformation due to collision from the vehicles, for example.

4. Analysis Results and Discussion

The analysis results of this study are analyzed from the data of 3 parts explaining in the passed sections. The study has concentrated on the types of damage and theirs causes which affect the damage of tower structures. Identically, rust covering on the tower structures is the main type of damage. The levels of rust covering have been descending arranged to be industrial, city, rural-II and rural-I area. The corrosion of structures is the most generated at the joints between the end of leg members and base of tower structures. By descending arranging, the step-bolts, ladders and joint connections are also the structure that corrosion is presented. Some members are abnormally more covered by rust whereas some members of which the same structure are rust free. Some towers exhibit the large settlement. Moreover, some members at the bottom of tower structures are stolen or deformed.

The factors that effecting the degree of deterioration and the causes of such above damages may be the location of tower, environment, landscape and climate. These factors all are the main causes of corrosion on the tower structures. The unsuitability on construction methods, transportation and material stock including the out-of-standard member production or selection the standards conflicting to the environment can accelerate the corrosive processes. Besides that, people who do not realize on the importance of transmission tower might steal or destroy the structure members and that incur the loss more rapid than the corrosion. As the results, the tower structures eventually will be fail.

5. Conclusion

From collecting the data and the relationship between the level of rust covering and age of tower for each area can be divided the investigation into 2 types as explained in flow charts.

- Figure 2 has shown the chart of basic investigation.
- Figure 3 has shown the chart of elaborating investigation.
- Figure 4 has shown the chart of operation system for elaborating investigation.

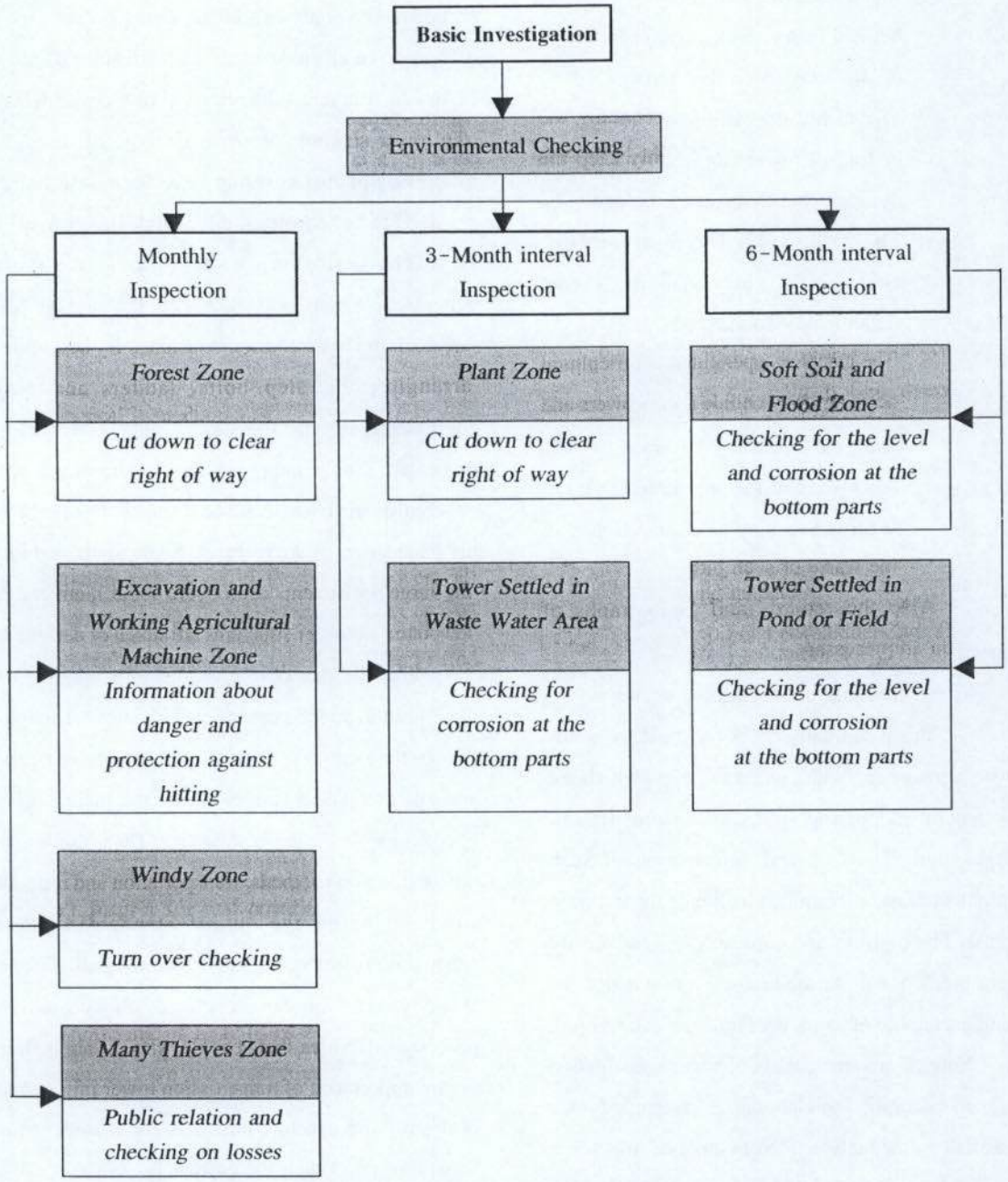

Fig. 2 Chart for Presenting the Basic investigation

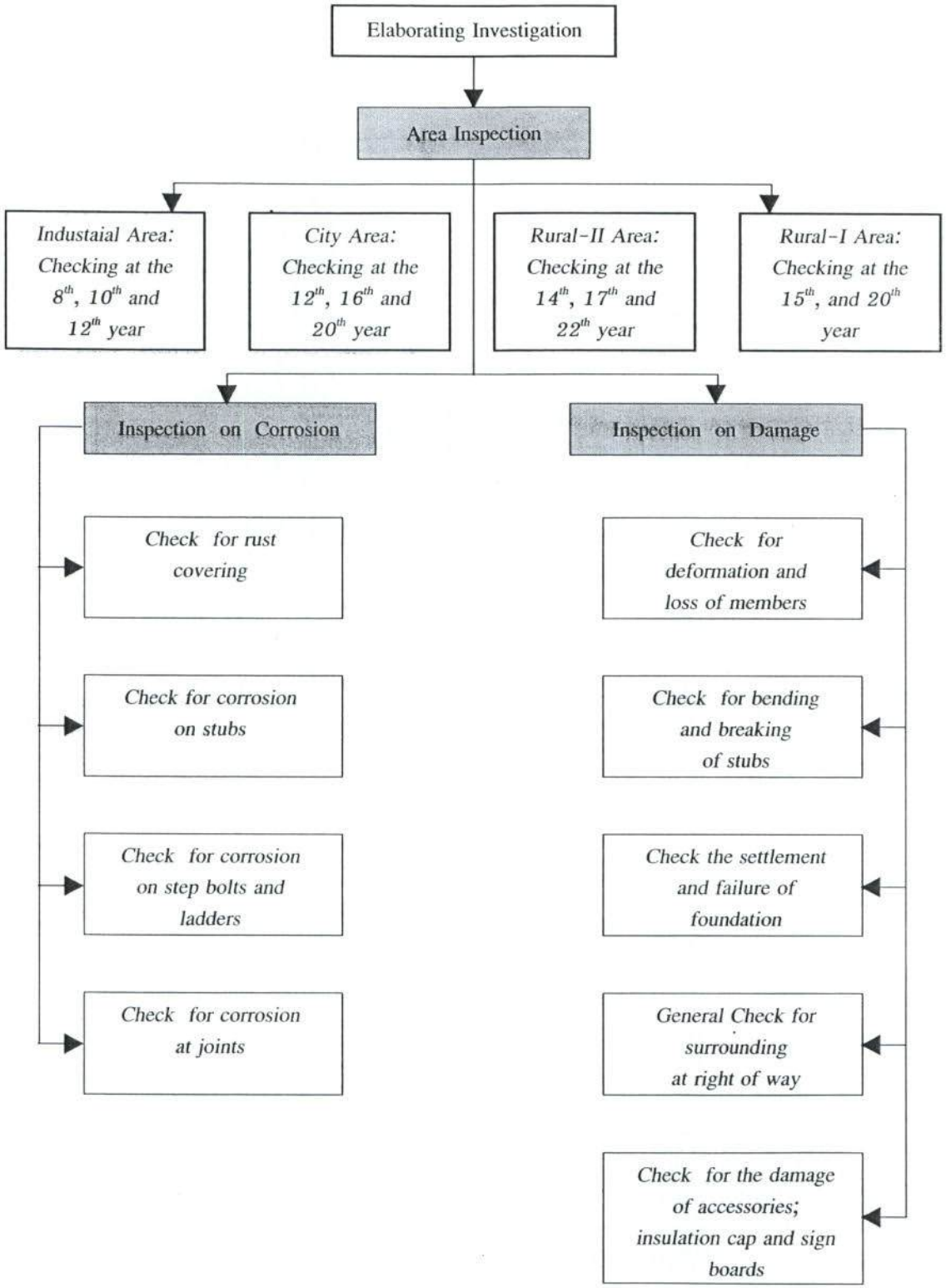

Fig. 3 Chart for Presenting the Elaborating investigation

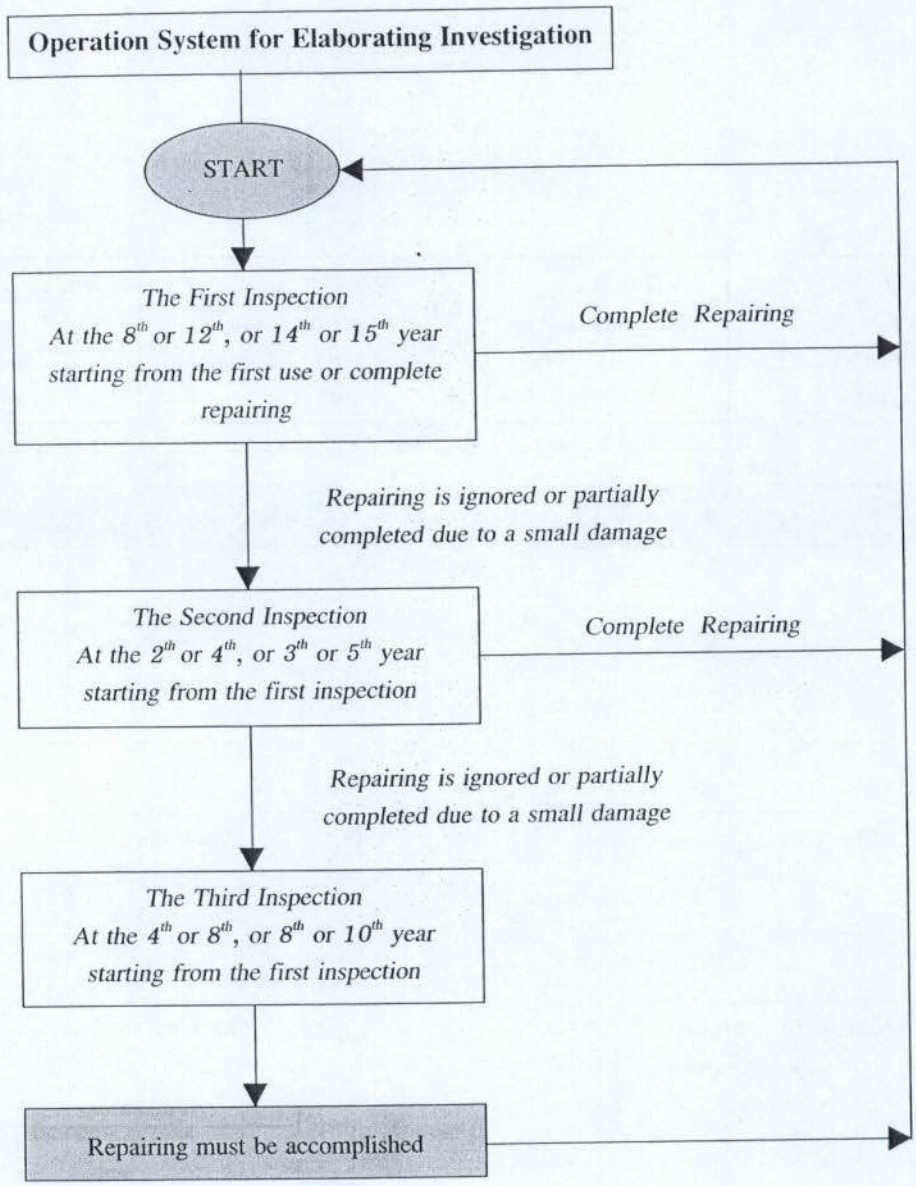

Fig. 4 Chart for Presenting the Operation System of Elaborating investigation

Consider on the figure 4, the order of checking period is presented as follows: industrial, city, rural-II and rural-I area, respectively.

The repairing includes re-painting and maintaining the structures from the damages. These damages can be repaired and also the operation of basic inspections, which are repairing, replacing and re-painting some of structure members, can be done simultaneously.

6. Suggestion

Standard and suitable transportation process, storing method and construction procedure, including the providing of the protection method and

maintenance as well as giving knowledge to the local people. This could extend the lifetime of the transmission towers and can be used to develop the standard for tower design in the future.

7. Acknowledgment

The author would like to give thanks to EGAT for useful helping in field observation and providing useful information. The author also would like to give special thanks to Asst. Prof. Dr. Somkiat Rungthongbaisuree and Mr. Tin Ketratanaborvorn for his corporation and useful consultation in this research.

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