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Analysis and testing the Over Head Transmission Steel Towers

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Abstract: *In this paper the method of design and testing the transmission line of high voltage steel towers is presented, the test loads were based on the design loading cases, all loads were applied on vertical, longitudinal and transversal directions though wire ropes by using power winches. Loads were measured at specified points at tower body using the load-cell strain digital system the test method, the load increment and the result interpretation was according to international standard of loading test of over head line structures IEC 60652.*

I. Introduction

Most transmission towers are designed to support one or two circuits, although some have been designed to support three or four circuits. Each circuit consists of three phases.
Transmission towers are of three general types:
Tangent towers are used where the line is straight or has an angle not exceeding 3̊ . they support vertical loads: transverse and longitudinal wind loads: a transverse load from the angular pull of the wires: and a longitudinal load due to unequal spans, forces resulting from the wire-stringing operation, or a broken wire.
Angle towers are used where the line changes direction by more than 3̊ .they support the same kinds of load as the tangent tower. The number of groups and the range of line angle in each group depend on the layout of the line.

Dead-end towers(also called anchor or strain towers) must take and dead-end pulls from all the wires on one side, in addition to the vertical and transverse loads. Because of the large duplication of tangent towers (70 to 80 percent of all the towers in a long line) the designer should focus his attention primarily on this type. Three items should be considered: cost of material, cost of erection, and cost of foundations. The cost of the material is directly related to the weight of the tower. The cost of erection is directly related to the number of pieces and number of bolts to be installed. The lightest tower may not be the most economical if it contains many more pieces per ton than a slightly heavier one, because more pieces must be handled in fabrication, shipment, storage, and erection. The cost of foundations is directly related to the spread of the tower legs. A tower with closely spaced lags will have shorter lacing members, but the higher stresses in the legs will increase foundation costs.

II. Load/Strength Design Mathod

The reliability-based design methodology that forms the framework for the loading guidelines. A load and resistance factor design (LRFD) format is presented for the design of any transmission structure. The nature and variability of loads are given along with detailed procedures for the selection of the load and resistance factors in [1]. This selection has a paramount effect on the reliability and cost of the line. The same design loads and load factors apply to structures made of steel, reinforced concrete , wood , or other materials, with only the resistance factors differing with material and component type.
One of the most important features of the LRFD method described in [1]is that it gives the designer knowledge of how much the reliability of a transmission line component changes with different values of the load and resistance factors. Line and component reliability factors are introduced that allow the designer to select load and resistance factors that will adjust the relative reliability by a known amount , the ability to assign relative reliability values to various lines and components within a line is an extremely useful concept.
Ref [2]provided in design guides for steel lattice, steel pole, wood pole, and concrete transmission line structures, and Ref]3[give design guides for steel towers.

WEATHER-RELATED LOADS

The specific procedures and formulas for determining weather-related loadings on transmission structures that can be used in the reliability – based design methodology outlined in [2, 3]. Weather-related loads are associated with wind, ice, or combination of wind and ice. In certain cases, temperature, atmospheric pressure, and local topography influence the magnitude of weather-related loads. Weather-related loads are sometimes referred to as “ reliability – based” loads (IEC 2002).

SPECIAL LOADS

The transmission line towers exposed to special loadings such as longitudinal loads, construction, and maintenance loads, line galloping, and structure vibration.

Longitudinal loadings may be the result of weather – related events, broken wires, or failure of an adjacent structure and must be resisted to prevent cascading failures of the support structures in the line. For this reason , longitudinal loadings are sometimes referred to as " anticascading" failure containment" or " security" loads.

Construction and maintenance loads must be specified to prevent structure member overstresses during construction or maintenance operations that may cause serious injury to workers. For this reason, these loads are sometimes referred to as " safety" loads.

Although galloping structure vibration do not generally produce extreme loadings on the structures, loads produced by galloping wires can damage crossarms, crossarm connections, and hardware. Furthermore, some structure member shapes are particularly susceptible to wind-induced vibration and have failed in fatigue. Consequently , the designer must be aware of the potential problems associated with these phenomena.

The designer should has full knowledge about all accessories whichwill be erected on the line such as insulators, spacing dampers… ect the insulator is the element will transfer the wind load from the conductors or earth wire to the tower, there are some of previous studies[4,5,6] which address this type of effect.

The structural analysis of transmission line towers

The transmission line towers are space steel structures which are modeled as space trusses and solved by using finiteelement method, the most famous program of analysis and design the transmission tower is called TOWER , but before using this program one has to know the cases of loading of each tower. Each case of loading depends on a number circuits and number of earth wire or fiber optical ground wire (OPGW) carried by each tower , and also depends on loading conditions(member of conductor broken …ect) and so on, the number of case loading as shown in fig (1) can be expressedas an example.

$$c_{n=1,81} = \sum_{i=0}^{3}\sum_{j=1}^{27} f_{ij}$$

Where c_n = case loading and f_{ij} case number for example

$C_1 = F_{11}$ —— means the wind in transfers' direction and no wire broken .

$C_4 = F_{24}$ —— means the wind in longitudinal direction and two lower left conductors are broken .

After the tower is analyzed according to the above loading cases , the tower members and the tower foundation designed according to the maximum load produced from these case of loading with defined factor of safety, then the proto type of tower is manufacture and erected in the test station for testing according to the test station for testing according to the teststeps stated in TEC [7] specification , but before carried on the test there are some questions to be answered by the designer inorder to convince the client and these points were not clear in TEC specification these point are:-

- How many loading cases should be applied on the tower during the test and on what base these loading to be selected ?
- Which case of loading can be carried for distractive of the tower .
- The designer should give clear picture where he expect the place of failure.

In this paper the tested 400 kv double circuit tower is presenters in following steps

- The tower test was carried out in according with client specifications [8]and basedon.
- The type of tested tower : 400 kv (AA) tower in condition of maximum two conductors broken or one conductor broken and earth wire broken .
- The tower was fabricated according to the design calculation, and erected in the test station after galvanized according to client specification .

METHOD OF TOWER TEST:-

The tested tower was erected on the specially fabricated base and wires connected between tested tower and anchor towers.

The test loads were based on the design loading cases as shown on fig (1) .

All loads were applied on vertical, longitudinal, and transversal directions respectively through wire ropes by using power winches

All loads were measured at the points of load application on the tower using the load-cell strain system.

Load test sequence :-

Load case no (**1**) vertical load only (erection case) .
Load case no (**2**) ant cascading (erection case).
Load case no (**3**) Transverse wind and both lower right conductor and ground wire are broken .
Load case no (**4**) Transverse wind and both middle right conductor and ground wireare broken.
Load case no (**5**) Transverse wind and both upper right conductor and ground wire are broken.
Load case no (**6**) Transverse wind and stringing case .
Load case no (**7**) Transverse wind no broken wire condition .

CALIBRATION OF LOAD CELLS:-

The load cell used in testing must be calibrated before and after the tower testing and also the electronic total station (surveying tools) used for measuring the deflection must be calibrated.

MEASURMENTS OF DEFLECTION:-

The deflection of the tower was measured by electronic total station in transversal face at three (3) points, and longitudinal face at three (3) points on tower in each loading case.
Locations of measuring deflection are shown fig (1).

Review of International Electro technical commission (T. E. C) specification for loading tests on overhead line towers[7]**:-**

The first draft of this specification was presented and discussed in Melbourne in 1975 , the second draft was submitted to the committees in 1976 the first published of this specification in 1979 and in 2002 this specification was updated , the table (1) and table (2) give a comparison between these publications .

Table(1)the allowable accuracy between the design load and measured applied load per step according TEC specification for both 1979 and 2002 edition:

LTEM	1979 PUBLICATION	2002 PUBLICATION
Load steps as % of ultimate load.	25% , 50% , 75% , 90% ,95% ,100%	50% , 75% , 90% ,95% ,100%
Adjustment of loads per step	25% (23% - 27%)	
	50% (48% - 52%)	(49- 51)%
	75% (73 - 77)%	(74 – 76)%
	90%(88 – 92) %	(89 – 91)%
	95%(93 – 97)%	(94 – 96)%
	100%(≥ 100%)	(100 – 102)%
Duration of load application	For the final	
	100% step	Minimum 1 min
	The loads shall	Max 5 min
	Be maintained 1 min	

Table(2) material criteria of accepting the test results according to TEC specification:

LTEM	1979 PUBLICATION	2002 PUBLICATION
Quality of material used for prototype	**1-**The client shall consider the test satisfactory if bending and compression members with slenderness ratios smaller then 150 for steel and 100 for aluminum (or any aluminums alloy) , and tension members, have the following average yield points: **a.** Steel or aluminum members having a minimum guaranteed yield point lower or equal to 300MPa: average value≤ guaranteed minimum × 1.25: **b.** Steel or aluminum members having a minimum guaranteed yield point greater than 300 MPa: average value≤ guaranteed minimum × 1.17: The averages are obtained from eight test specimens taken from eight different most heavily loaded members of the structure for each grade of material. **2-**However , for members with slenderness ratio higher than those indicated in sub-clause (1) and for redundant, the above	The material used in prototype shall be representative of the materials used in production structures and within the appropriate industry specification .

	limits may be exceeded since their yield point has little influence on their collapse. **3-**For the average value of the ultimate strength, the following limit shall be accepted: average value≤ guaranteed minimum × 1.20: the average is obtained from the eight test specimens used for the determination of the average value of the yield point of the material. If all these conditions are not satisfied, the test is not valid and the prototype shall be rejected.	

Load test sequence and observation:
the load test sequence carried according to agreed load test cases are given in table (3) and also shown in figs (2, 3, 4).

Deflection limits of structures

The specification did not gave limitation for the deflection of the towers, specially the permanent deflection on structures , from figures [1, 2, 3].

III. Discussion of the results:

It is clear the tested tower was designed in poor way , and the damaged members were not the members expected be damaged even the they were designed with higher factor of safety which means the test was not reflected the behavior or the real structure , and the measured deflection does not show the real behavior of structures , which indicated the applied forces on the tower by the test station wings were not reflection the design forces and were not homogenous in mean while the criteria of accepting or rejecting the tested tower defined by TEC specification is not well defined if one applied the criteria specified by TEC in 1979 meanly the material criteria the result of tested tower is failed but according to the criteria defined in 2002 by TEC specification the result of tested tower is accepted

IV. Conclusion:

It is clear IEC specification did not clearly defined the criteria of a accepting or rejecting the test results and also it did not put any limitation to permanent deflection .

Table (3) THE LOAD TEST SEQUENCE TABLE RESULTS AND OBSERVATION

LOAD TEST	DAY	LOAD SEQUANCE	WAITING PERIOD MIN	REMARKS
LOADS TEST # 1	1	50% ……….. 100%	1	No failure
LOADS TEST # 2	1	50% ……….. 100%	1	No failure
LOADS TEST # 3	1	50% ……….. 100%	1	No failure
LOADS TEST # 4	1	50% ……….. 95%		After adjusting all the loads in vertical and transversal directions to 100% , and during increasing the load (L5) to 100 % the superstructure of the tower was twisted . (see photo fig (2)). The tower visually inspected by the designer and testing engineer. some main members was failed, then the designs decided to add some members and increase the size of some other members. The damage and modified members assembled and erected on the tower the test start again after one week on day 10^{th}.
LOADS TEST # 4	10	50% ……….. 100%	1	No failure
LOADS TEST # 5	10	50% ……….. 100%	1	No failure
LOADS TEST # 6	10	50% ……….. 95%	1	After adjusting all the loads to 95% and during reading the deflection at this step, the tower total fall down and completely destructed. The failure started at the lowest part of leg extension in compression side. (see the destruction photo fig (3)). After studying the tower failure the designer added the some new members to the strut face in leg extension. The contractor fabricate a new tower and after assembled

				and erected of this tower the test started again on day 14th in the pillowing sequence:-
LOADS TEST # 6	14	50% ……….. 100%	1	No failure
LOADS TEST # 1	14	50% ……….. 100%	1	No failure
LOADS TEST # 2	14	50% ……….. 100%	1	No failure
LOADS TEST # 5	14	50% ……….. 100%	1	No failure
LOADS TEST # 7	14	50% ……….. 95%	1	After finishing one minute at 100% , the load values increased to 105% , the tower destructed Just after adjusting all loads to 105%, at the lowest part of leg extention . in compression side(see fig (4)).

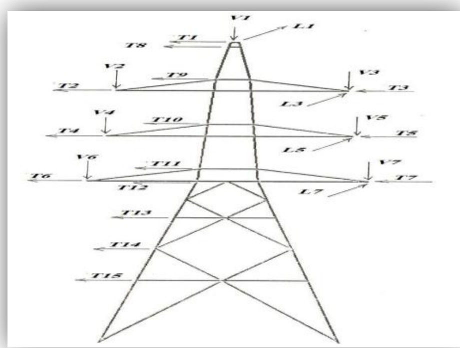

Fig. (1)
Load Mark for Load Cases

Fig. (2)
Test No. (4) 95% Loading

Fig. (3)
Test No. (7) 95% Loading
Assumption: (T1) first failure (Destruction Test)

Fig. (4)
Test No. (7) 105% Loading
Assumption: (T1) second failure (Destruction Test)

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