PACIFIC LIGHT and POWER CO.

Investigation of Transformer Burn Outs at Kern Substation.

for

Mr. W. Woodbury, Engineer of Construction

by

R. W. Sorenson.

CONFIDENTIAL

REPORT

TRANSFORMER BURN OUTS
at
KERN RIVER SUBSTATION
PACIFIC LIGHT and POWER COMPANY

Preamble:-

When Mr. Woodbury told me of the frequent "burn outs" of the high tension windings of the 750 kv. a. transformers at the Kern Substation and spoke of his plan to use an oscillograph for the determination of the cause of these burn outs, it occurred to me that this would afford an excellent opportunity to put to use the oscillograph of Throop Polytechnic Institute. Following out this plan, Mr. Woodbury and I took the oscillograph, with its auxiliaries, to the substation on January 2nd, and made ready for the tests, which were commenced Saturday, January 4th. Subsequent to this time other records were made with the oscillograph, of currents and voltages at times of charging lightning arresters, and when switching, but as there was no indication of any transient phenomena worthy of consideration, this report, which is to be supplementary to that of Mr. Woodbury, will deal largely with the results of a number of tests on the transformer oil, as this seems to be the only thing which can be held responsible for the trouble.

Introduction:-

Early in the discussion of the trouble, Mr. Woodbury and I discussed the possibility of poor oil, and Mr. Woodbury tested it again for dielectric strength, which was found to be good, and further we made sure that the oil was supplied by the General Electric Company, for use in the transformers, so that the oil question was dropped until on January 16th Mr. Ralph Bennett mentioned to us, at lunch, that it was common practice here in the West to use California oil from Point Richmond, and that the Great Western Power Company had found trouble due to this oil having sulphur in it.

In 1907 my work had brought me into contact with a large amount of transformer trouble, that was eventually traced to the action of sulphur, in the oil, upon the copper of the windings, the sulphur in this case being present by

reason of its having been used to seal the leads into the transformer bushings.

Having in mind these things, it seemed well to really study the oil and see if it did contain sulphur; so two samples were selected for a preliminary test, with the results given under the heading "Group I", after which the other two tests were made.

Methods of test:-

Two methods of making tests were applied to all samples under consideration, which, for convenience in making this report, will be styled the Copper Test, and the Sulphide Test.

The copper tests were performed as described in a paper entitled "The Dielectric Strength of Oil" by H. W. Tobey, published in the Proceedings of the A. I. E. E. for June 1910, from which the following table was taken:

TABLE

of time required for oil containing sulphur to blacken copper when heated to 85 degrees Cent.

Per cent sulphur.	Time required to blacken copper wire
1/10 of 1 per cent.	2 to 3 minutes
1/100 " 1 " "	30 minutes
1/1000 1 " "	15 to 20 hours
1/10000 1 " "	Uncertain

The Prusside test, or more properly, the test for sulphur by the use of sodium nitro prusside, is best performed by taking a small quantity of oil into which a piece of metallic sodium has been dropped, and heating until the oil is completely distilled off, leaving only carbon and sodium sulphide, Na_2S. This residue is then washed with distilled water and filtered, and a few drops of the prusside solution added. If sulphur is present the addition of the prusside will cause violet purple streaks to be formed for a short time, after which the solution will turn brown. This test is recognized as standard among oil men, and while more delicate than the copper test, it will not detect sulphur in quantities as minute as other tests used by chemists.

OIL TESTS

Group I

The tests under this group were two in number - one on the first sample of the old oil; that is, the No. 8 transil oil which was put in the transformers in December 1910, and the other on a sample of the new oil which has just been put into one of the transformers rebuilt with new coils. Both samples were drawn from the oil gauge cock of the transformers. These samples were tested by taking a test-tube of the oil and placing in it a carefully cleaned piece of copper wire, which was then treated as described under the heading "Methods of Tests", the three minute test only being applied. As a result of this treatment the copper in the sample of old oil turned dark, whereas the piece in the new oil was apparently unchanged, and hence it was deemed advisable to continue the work, and other samples, as described under the other groups, were obtained and tested.

Group II

This group was made up of nine samples taken from the tops and bottoms of several of the transformers, with the exception that the sample from Transformer No. 2, Bank 2, which had burned out, was taken from one of the drums into which the oil had been drawn. The samples in this group were carefully marked and tested by both the copper test and the prussiate test, with the results given in the following table.

Table for Group II

Sample No.	Transformer No.	Copper Tests			Sodium Nitro Prusside Tests	Remarks
		3 min.	30 min.	24 hrs. or longer		
Trans. 2 Bank 2	232454	None	slight	strong	strong	B. O. sample from drum
Original old oil sample (Top)		?	stain	black spots	certain	Same as sample of Test I group Top
Trans. 3 Bank 4 (Top)	232460	None	slight	black	certain	Top
Trans. 3 Bank 1 (Top)	232453		slight	spots, and black	certain but not strong	Several test tubes full tried. Top. Results checked
Trans. 3 Bank 1 (bottom)	232453		slight	black	stronger than top.	
New Oil Drum				slight	certain, not strong	Several tubes tried.
Trans. 1 Bank 1 (Top)	232451			slight to very black	certain	Several tubes of oil Tried)top)
Trans. 1 Bank 1 (bottom)	232451		slight	black	medium	2 tubes full used. Results checked
New Oil	232460		slight	slight	certain	Same as Test I. Group

Group III

This group consists of 12 samples, one from the top of each transformer at the Kern Substation. These samples were originally drawn by Mr. Woodbury for the General Electric Co. but were declined by them as they wished to use their own bottles.

Sample Number	Transformer Number	Copper Test			Prusside test	Remarks
		3 min.	30 min.	24 hrs.		
1	232451	Neg.	slight	slight	slight	
2	232455	Neg.	slight	slight	slight	
3	232453	Neg.	slight	slight	definite	
4	232459	Neg.	?	slight	positive	
5	232454	reddish tint	stronger	strong	strong	B.O. 4-29-12 B.O. 1-7 -13
6	232458	Neg.	Neg.	?	Neg.	B.O. 1-20-13
7	232456	Neg.	slight discol.	?	very slight	
8	232461	Neg.	?	?	Positive	
9	232452		?	definite	Positive	
10	232457		?	slight	slight or ?	B.O. 6-18-12 B.O.11-30-12
11	232462		?	?	Neg.	B.O. 8-18-12
12	232460		?	slight	slight	B.O. 10-4-12

Note; Samples 10, 11, and 12 are new oil first put into rebuilt transformers with new coils. Old oil which had been drawn off and put into drums tested in Group IV, samples designated as B.O. # 4 book, There are three of these which were taken at random from the drums

Eagle Rock Substation, undated
Kern Substation, 1913

Group IV.

This group contains samples from the Kern Substation, the Redondo Power plant, and a sample from a 500 k.v.a. transformer shipped complete and full of oil, from the East.

Sample	Trans. No.	Copper test 40 hour, at 87 deg. C.	Prussido Test	Remarks
A-4 Top		Spotted	Definite	
A-4 Bottom		?	very slight	
B-4 Top		Negative	slight	
B-4 Bottom		?	slight	
C-4 Top		Negative	negative	
C-4 Bottom		Negative	Positive	Copper tested for. CuS with Cu acetate, with positive results.
A-5 Top		?	slight	
A-5 Bottom		Slight	positive	
B-5 Top		?	positive	
B-5 Bottom		?	positive	
C-5 Top		Spotted	positive	
B.O. No. 4 Bank (1)		Black	strong	these 3 samples selected at random from drums into which oil had been drawn after B. O.
B.O. No. 4 Bank (2)		Black	strong	
B.O. No. 4 Bank (3)		Black	strong	
Extra trans. top		Negative	Negative	
Extra trans. bottom		Negative	Slight	
New H-B oil		Negative	very slight	
500 K.v.a. oil		Negative	Negative	Repeated carefully 3 times with same results.

Rock Substation, undated
ts at Rock Substation, 1913

Group V.

This group or set of tests was made to check the results obtained in samples 6 and 7 in Group III, by testing new samples from those transformers. New samples are 6A and 7A, the others being added just to check some previous results as to the copper test only.

Sample No.	Trans. No.	Copper Test 3 min.	30 min.	24 hrs.	48 hrs.	Prussiate Test
6	232458	Neg.	Neg.	Neg.	Neg.	
6A	232458	Neg.	Neg.	Pos.	Black	Positive
7	232456	Neg.	Neg.	Neg.		
7A	232456	Neg.	Slight	Slight	Slight	Postive
Bank4 Trans. 3	232460	Neg.	Neg.	Pos.	Pos.	Positive
8	232461	Neg.	Neg.	Slight	Slight	Positive
New oil (1)		Neg.	Neg.	Pos.	Black	Positive
10	232457	Neg.	Neg.	Pos.	Stronger	Slight

Tests on Copper from the Burned Out Transformers.

Some pieces of the copper conductor were selected at random from the top end and from the bottom end of the windings in the burned out transformers, the pieces being taken from the coil in which the burn out had occurred. These pieces were examined for signs of copper sulphide on them, and as a general thing a dark brown or black stain could be found on the surface of the copper exposed to the oil, this stain not being found on the inner edge next the collar, but it extended about half way in between turns. Pieces of copper showing this stain were cut off, placed in a test-tube, covered with dilute hydrochloric acid, and heated slightly until bubbling started. A piece of filter paper which had been dipped into lead acetate, $Pb(C_2H_3O_2)_2$, was held at the mouth of the tube and it turned a dark brown or black, showing that a considerable amount (relatively speaking) of hydrogen sulphide (H_2S) was being given off, and hence proving that some of the deposit on the copper, which by the way was dissolved off by the hydrochloric acid, was copper sulphide.

This test was repeated several times with the same result in each case.

Oscillograph Tests.

As mentioned in the preamble a number of oscillograph records were made, as shown by the list following, but as each of these is what might be called a perfectly normal curve, it is quite evident that none of the trouble is fundamentally due to lightning arrester charging at the sub-station, or at Borrel, or to normal switching conditions at the sub-station. In fact, on January 4th, when the original oscillograph records were made a very high wind was sweeping over Southern California, and the lightning arresters were caused to discharge viciously currents so large as to blow the fuse of the current shunt on the oscillograph being sent through the shunt, (see diagram) without any noticeable voltage disturbances taking place, thus showing the lightning arresters to be working very well.

List of Curves Taken with Oscillograph

Curves of Potential on high tension and low tension sides, and of current, when energizing bank of transformers from low tension side.

Curve showing potential wave only of system as taken at Kern Sub-station. (normal operation)

Curve showing voltage and current waves of power from Kern River energy delivered to L. A. Ry.

Curves of line potential, and current in arresters, when charging arresters at Kern Substation; of potential at Kern Sub-station when charging arresters at Borrel.

The original films of all of these curves are on file with Mr. Woodbury.

Wave Form Analysis.

An approximate analysis was made of the form of the potential wave designated as "Kern Sub. P. L. and P. system, potential wave", and the wave was found to contain quite a pronounced third harmonic, together with a noticeable fifth harmonic, but as the low tension windings of the transformer are connected delta, this should cause no particular trouble, as it is of no greater prominence than that found in many systems operating without any trouble whatever.

Confirmation Tests

To prove that the color upon the test pieces of copper used in the copper test for copper sulphide was really due to copper sulphide, I cut up some of the pieces of wire upon which the stain was produced, subjected them to the test described for the testing of the stain on some of the copper from the burned out transformers. Each of the several samples tested showed that the deposit was copper sulphide; and further, a test on some of the clean wire used for the copper test samples showed that it had no copper sulphide deposited upon it.

Test to Determine Conductivity of Copper Sulphide.

Some copper sulphide was made by making a solution of about two ounces of copper sulphate ($CuSO_4$) in distilled water, and passing through it some hydrogen sulphide (H_2S) thus precipitating CuS in water, and (H_2SO_4), sulphuric acid, The sulphuric acid was then washed out and the copper sulphide dried.

To test its conductivity, the bottom of a beaker about two inches in diameter was covered with this powder to a depth of 1/4 inch, and current made to pass through it and a meter in series, and through it and a lamp in series. This the current did, as readily as would be the case if carbon dust, or pieces of metal were substituted for the copper sulphide, thus proving the sulphide to be a good conductor.

Conclusion:

As a result of these tests it seems entirely reasonable to suppose that the transformer trouble at the Kern Substation is due largely, or entirely, to sulphur in the oil, for the reasons which may be briefly summarized as follows:-

1st. Insulation of transformers is in good condition.

2nd. No trouble was experienced until oil had been changed, and system has not been materially changed in any way prior to, or during, time of trouble.

3rd. All published data on transformer oil, of which there is very little, specify that the oil shall contain no sulphur.

4th. Sulphur could cause trouble in two ways: (a) narrow cross section of copper until it becomes excessively hot, (b) deposit copper sulphide across the insulation between turns, thus causing current to start across.

5th. Sulphur, when found in oil at other places, has caused great damage.

Recommendation:-

In no case should oil which shows the presence of sulphur by the "copper test" be used, and it would be preferable to use oil which, when given a prusside test, made by distilling off 10 c.c.m. of oil into which there has been placed a small piece of sodium, shows no sign of sulphur.

This requirement is specified because oil can be obtained which will meet it, and because the copper test does not seem to be certain in that when two pieces of copper cut from the same wire are placed in one sample of oil, it frequently happens that one will stain and the other will not.

Signed:- R.W. Sorensen

Throop Polytechnic Institute,
February 28, 1913.