THESIS

THE DESIGN AND CONSTRUCTION OF A SYNCHRONOUS COMMUTATOR FOR HIGH VOLTAGES

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The
Design and Construction
of a
Synchronous Commutator
for
High Voltages.

A Thesis
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the Faculty
of
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by

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Preface.

The object of this thesis on the construction of a synchronous commutator, was primarily to provide a means of obtaining a high potential direct current, and secondarily, for the purpose of leaving something more than a typed copy of a summation of ideas. It has been the desire of the authors to produce something tangible which would be useful and which could be left as an addition to the apparatus of the Electrical Engineering Department.

In the design and construction of this apparatus but few derivations, calculations, and standard formulae could be used. This is because of the fact that there is but little data available on this type of rectifier and the work of this thesis is largely experimental. The working qualities and precision of any apparatus approach the highest desirable standards only after much designing building, rebuilding and improvement. This being the first apparatus of its nature to be brought into the department, it is the hope of the authors that it may further the incentive, and furnish the starting point for further experiment and research along the line of synchronous commutators

In choosing the methods of procedure and determining the lines along whigh the construction should proceed, the authors are greatly indebted to Professors A.R.Sawyer M.M.Cory, L.S.Foltz and E.E.Kinney of the Electrical Engineering Department for their supervision, advice and many timely suggestions. We wish also to thank Mr.A.P. Krentel of the Wood Shop and Mr.G.C.Wright of the Machine Shop for their many accomodations and their kindly assistance.

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Discussion.

Electric currents are classed under two general headings: alternating and direct. Oftimes both are needed where only one is available and it then becomes necessary to devise some means of conversion whereby one type of current may be changed to the other. There are many methods of bringing about this change, and each method has its advantages and applications. The most important methods of rectification are:Rotary Converter, Motor Generator, Mercury Arc Rectifier, Vacuum Tube, Vibrating Rectifier, Electrolytic Rectifier Point to Plate Discharge Rectifier,and the Synchronous Commutator. Of these the most common are the rotary converter, motor generator and mercury arc rectifier. The vibrating rectifier is also commonly used with small battery charging outfits. For the conversion of large amounts of power the rotary converter is undoubtedly the best adapted, and it can be used for conversion of A.C. to D.C. or D.C. to A.C. The motor generator set is usually more costly, while the mercury arc rectifier is limited in size and application.

Among those thus far discussed, there are none which are adaptible to high potentials. The point dischage rectifier and the synchronous commutator are the only ones which lend themselves to use with high voltages.

Of these, the poimt discharge rectifier is at once eliminated, since it uses only one half of the A.C. wave and is consequently very inefficient.

The synchronous commutator is atype of rectifying apparatus which may be constructed to meet nearly any condition of potential or current.It has the one disadvantage that it does not give satisfactory results when operating inverted,(i.e., converting D.C.to A.C.) as does the rotary converter. On the other hand, the rotary converter or motor generator can not be be used in handling high potentials on account of insulation troubles.

Seeing the need of a machine which will produce direct current at high voltages, the authors have designed and constructed a synchronous commutator which will convert high voltage A.C.to D.C. at the same voltage The design and construction are discussed in detail on the pages following.

The Commutator.

A synchronous commutator such as is herein described, is a machine which rectifies alternating current and produces direct current from it, The resulting current is a direct current in that its flow is in only one direction, but in a strict sense it is a pulsating current, the pulsations all being in the same direction.

The fundamental principle of the commutator is that of a reversing switch which reverses contacts when the alternating current reverses direction. The reversing of contacts must be periodic and of twice the frequency of the alternating current to be rectified. These conditions are most easily brought about by a commutator which rotates at synchronous speed. Around this commutator are placed brushes to furnish the alternating current and to carry away the direct current.

With a 60 cycle current and a synchronous speed of 1800 r.p.m. there would be two 90 degree segments on the preiphery of the commutator 90 degrees apart. Then, at the instant that an A.C. brush was positive, one segment would connect between the A.C. brush and the positive D.C. brush.

As the A.C. brush becomes negative the segment rotates to a position such that it now connects the same A.C. brush to the negative D.C. brush, and simultaneously the opposite segment connects the other A.C. brush, which is positive, to the positive D.C. brush. Thus we see that the D.C. brushes maintain the same polarity though the A.C. brushes are rapidly changing from positive to negative.

The commutator herein designed is to be used for high voltages. The high voltage A.C. is obtained from a special transformer. Thisntransformer was equipped with a magnetic shunt wherby the secondary voltage can be varied from a small potential to about 20,000 volts.Commutating difficulties are often experienced with high preipheral velocities but with such high potentials it is not necessary that the brushes make actual contact with the commutator segments, thus this difficulty is easily overcome.

One of the most important factors in the design of the commutator is the voltage at which it is going to be used. The next factors of importance are; the speed of rotation, number of poles, and current carrying capacity.

One inch separation is commonly considered as sufficient insulation between conductors carrying 20,000 volts. But, due to arcing between the brushes, and the segments, especially at the breaking points; i.e. when the segments leave the brushes, this separation of conductors must be increased considerably. In designing the commutator provision was also made for later using it at higher voltages. Since the brushes do not make actual contact with the commutater, the commutater is not affected by the peripheral velocity, and the diameter of the commutater is then limited only by its mechanical strength. A commutator diameter of 10 inches was deemed the best under the existing conditions.

Excepting the rotary converter and the mercury arc rectifier, most rectifying apparatus is not very efficient. This is because of the fact that only a part or parts of the alternating current wave are rectified. The commutating rectifier is inherently more or less inefficient due to its mechanical construction. In order that it might rectify 100% of the A.C. wave, if would be necessary that the brushes subtend an arc of 180 electrical degrees.

This is obviously impossible for the tips of adjacent brushes would then be in contact and produse a short circuit across the high voltage A.C. source. Thus we see that decreasing the length of the brushes increases the gap between them and increasing the length of the brushes increases the portion of the wave that is rectified. The most satisfactory length of brush is about 90 electrical degrees, which is equivalent in this case, where there are two commutator segments, to 45 mechanical degrees.

The potential of the rectified current depends upon that of the part of the A.C. wave which is rectified. If the phase position of the brushes is such that the highest portion of the wave is rectified then the potential of the direct current will be the same as the maximum A.C. potential. The D.C. potential may be varied from a maximum to nearly zero by varying the phase position of the brushes.

The brushes were constructed of #16 gage brass strips 5 inches long, covering an arc of 45 degrees. The four brushes were held by lock-nuts upon 1/8 inch iron pipes 3inches long. The brushes and holders were supported by four cross arms 90 degrees apart.

See Fig.1. To the center of the cross-arms was attached a ½ inch rod which was free to rotate in its support, but held in any position by friction. See Fig.2.

With this arrangement the phase position of the brushes could be set or varied at will, and would remain in the position set.

Figures 1,2,3 and 4 show the construction and arrangement of the brushes and supports.

The Synchronous Motor.

Since the commutator whose construction was contemplated must revolve at synchronous speed, the problem resolved itself into that of producing a synchronous motor of sufficient power to drive the rectifying equipment. A motor of the type used on the oscillograph was considered but it was thought that such a motor, if built in the size necessary, would be extremely difficult to start, since the start would have to be made by hand.

Accordingly, the aim became: to produce a self-starting synchronous motor. A four pole machine was selected as being probably the best in respect to speed, for the commutating eqùipment and subsequent developments showed that a single phase machine would probably be the simplest to construct.

Having available an old Westinghouse fan motor of the single phase, four pole, shading coil type; it was assumed that the power from such a machine would suffice, and arrangements were made to produce a motor which would revolve at synchronous speed

The stator of the motor, shown as Fig. 5, is of the salient pole type, and it was planned to build a rotor having small clearance, with four salient poles and a superimposed squirrel cage winding. It was thought that such a machine would start as an induction motor, due to the shifting flux produced by the shading coils, and when near synchronous speed would pull imto synchronism. At synchronous speed it was expected to run in a manner similar to the oscillograph motor.

However, after building the motor as indicated, if failed to start, although, if started and brought up to synchronous speedit ran satisfactorily.

Since our aim was a self-starting synchronous machine, we were not satisfied, and decided to go on and produce such a machine even if we had to junk all our previous work and start over again.

On analysis of the situation, it developed that having salient poles on both rotor and stator, the rotor was in a position of least magnetic reluctance when the rotor and stator poles were opposite each other and the motor was unable to develop sufficient starting torque to pull the poles apart.

It seems that it might be possible to accomplish this by having a heavy enough shading winding. However, we were hampered in making any changes along these lines by lack of room on the stator. The rotor as used is shown in Fig.7.

The solution of the difficulty meant the construction of another stator with a distributed winding so built that the motor could start as a split phase induction motor and run as a single phase motor similar to the oscillograph motor.

It can readily be see n that the stator would provide a uniform magnetic reluctance at all times during a revolution.

Rather than to construct a stator to fit the previously constructed rotor, we decided to procure an induction motor and modify the secondary structure so as to be polar. The most accessible motor was found to be a 1/8 H.P. General Electric, single phase induction motor running at 1775 r.p.m.

The motor is built with the winding on the rotor and the secondary or squirrel cage winding on the stator. This, of course, meant that the stator would have to be made polar. The stator had 37 slots and, since it was desired to produce four salient poles, two stator bars were removed at each of four points as nearly 90 degrees apart as possible. The included tooth was then removed leaving four polar

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The motor was then assembled and run in this condition and was found to be almost but not quite synchronous in speed. Another tooth was then removed from each stator pole and the motor was found to revolve at synchronous speed wheh the applied voltage was 240. The rated voltage was 220.

Themawhine could probably be made synchronous at lower voltages by removing another tooth from each pole, but, since this would increase the exciting current it was deemed inadvisable.The stator as completed with its polar projections is shown in Fig.8.

The speed of the motor could not be determined accurately enough with a tachometer so to determine whether of not the motor was running synchronously the following was resorted to.

The motor shaft and generator shaft were fitted with projections on their ends which would touch when they passed each other, thus making an electrical contact. When running synchronously their relative positions were the same since the generator used was also a four pole machine. By connecting a telegraph sounder circuit to the

projections with magnets [illegible]
winding.

The rotor was then [illegible] in this condition [illegible] found to be almost but not quite synchronous in speed. Another tooth was then removed from each stator pole and the rotor was found to revolve at synchronous speed when the applied voltage was 1[illegible]0. The rated voltage was [illegible]20.

The machine could probably be made synchronous at lower voltages by removing another tooth from each pole, but, since this would increase the exciting current it was deemed inadvisable. The stator as completed with its polar projections is shown in Fig. 8.

The speed of the motor could not be determined accurately enough with a tachometer so to determine whether or not the motor was running synchronously the following was resorted to.

The motor shaft and generator shaft were fitted with projections on their ends which would touch when they passed each other, thus making an electrical contact. When running synchronously their relative positions were the same since the generator used was also a four pole machine. By connecting a telegraph sounder circuit to the generator and motor an indication of the difference in speed was obtained. A periodic clicking of the telegraph sounder indicated a difference in speed.

Another method of judgine whether or not the motor is running synchronously is to listen for "beats" or "hunting". If beats are perceptible it is reasonable to assume that the motor is not running synchronously.

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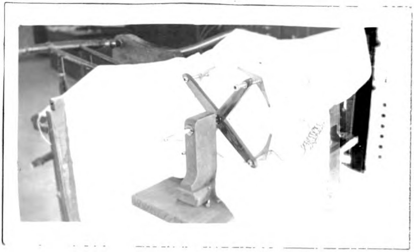

Fig.1.

Brushes, arms, and supports.

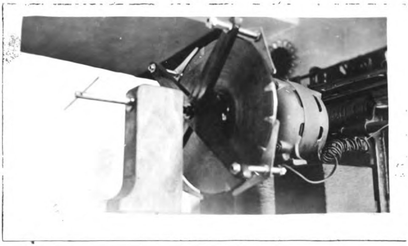

Fig. 2.

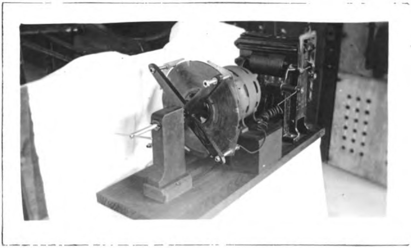

Fig. 3.

End view of apparatus.

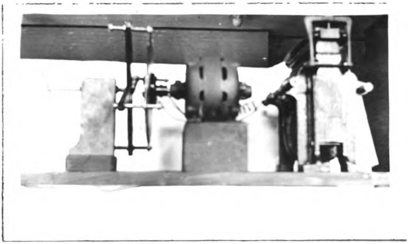

Fig. 4.

Side view of apparatus.

Fig. 5.

Stator of original motor.

Fig. 6.

Rotor of original motor.

Fig. 7 .

The wound rotor.

Fig. 8.

The stater as modified.

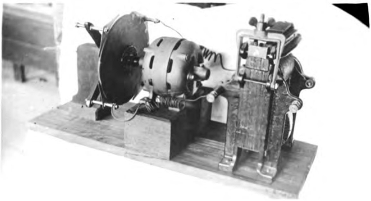

Fig. 9.

The complete machine.

Fig. 10.

The transformer.

Tests and Results

Having completed the construction of the synchronous motor and the rectifier, the two elements of the apparatus were assembled on a suitable base together with a transformer which was for the production of the high voltage alternating current. The assembly is shown in Figs. 3, 4, and 9. The transformer is shown in Fig. 10.

Since the apparatus was constructed, it was deemed necessary to test it to see whether or not it performed the work for which it was designed. The first test was made by connecting a thoroughly insulated D.C. milliammeter in the D.C. circuit which was shorted. The machine was set in operation and a small variable deflection was noted. This indication increased as the voltage was increased. The current was of the order of 30 milliamperes.

It soon became apparent that the machine was not suitable for any appreciable current, for with much current there was considerable arcing and consequent burning of the commutator.

Not feeling that the ammeter test was conclusive we then turned to the oscillograph to indicate more clearly and vividly what was taking place.

On account of the small current handled great difficulty was experienced in operating the oscillograph, and no oscillograms are shown because they were not satisfactory fot photographing. The oscillograph however, did indicate that a rectification was taking place. The direct current produced was not constant in value and had superimposed upon it a high frequency A.C. of the order of 1500 cycles. This we attribute to the fact that there is a spark gap in the circuit.

The oscillograph element was finally connected directly in the shorted high voltage D.C. circuit, although at first a shunt circuit was used to prevent injuring the oscillograph.

Great difficulty was experienced in operating the oscillograph due to the extremely high voltages handled.

Rotation of the brushes changes the wave form and polarity of the D.C. The best method of obtaining the brush setting for maximum output is to rotate them until a maximum spark length is obtained in a gap connected in the D.C. circuit.

Conclusion.

In view of the facts brought out by our tests, the following conclusions are drawn:

1. The method is not applicable to currents of more than 25 milliamperes. It is useful mainly as a source of high D.C. potential.

2. The D.C. circuit must be designed first and the machine designed to fit or the current handled may be excessive.

3. It is impossible to produce a uniform D.C. by this method.

Now the above does not mean that the apparatus is useless, but rather that its use is limited. For use in the production of current for a Cottrell Precipitation treate r it would undoubtedly be satisfactory. It might also be used in the s silent discharge process for the fixation of atmospheric nitrogen. The machine , however, is of a very special nature.

The authors, however, are satisfied that the construction and testing of the apparatus has brought out many important points which could not be gained otherwise. The literature available on the subject is very limited and the possibilities of the apparatus could only be learned by actual experience with it.

Conclusion.

In view of the facts brought out by our results, the following conclusions are drawn:

1. The method is not applicable to ozonizers of more than 10 million cycles. It is useful only as a source of high H.F. current.

2. The H.F. circuit must be designed first and the machine designed to fit or the current handled may be excessive.

3. It is impossible to get a uniform D.C. by this method.

Now the above does not mean that the machine is useless, but rather that the use is limited. For use in the production of current for a Cottrell precipitation treater it would undoubtedly be satisfactory. It might also be used in the silent discharge process for the fixation of atmospheric nitrogen. The machine, however, is of a very special nature.

The authors, however, are convinced that the construction and testing of the above machine has brought out many important points which could not be gained otherwise. The literature available on the subject is very limited and the possibilities of the generator could only be learned by actual experience with it.

We have left a piece of apparatus which is similar to nothing else posessed by the department and if of no other use it will at least show where the installation of such a machine cannot be considered.

It is suggested by the authors, that having now a small synchronous motor, it might be desirable for someone in the future to construct a commutator for it for use with some lower potential such as used in battery charging, for instance, and determine the characteristics of such an appliance.

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