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PARALLEL OPERATION OF ENGINE-DRIVEN ALTERNATORS.

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There has been and is much diversity of opinion and practice among engineers in relation to the operating of alternators in parallel from steam engines. This paper explains a method of overcoming the difficulties of such operation which has been in successful use for three years in many important installations.

The problem to which it relates is one of the greatest importance, and the solution described is, or is believed to be, complete and universal. It is, for every reason, desirable to the whole fraternity of electrical engineers, that differences of opinion and of method in such a matter be removed or reconciled. I hope, therefore, that this paper, with the discussions which may follow it, will serve either to establish generally the use of the methods proposed, or to bring about the general acceptance of other or improved means for accomplishing the same result.

The problem of operating engine-driven alternators in parallel arose in Europe before it attracted attention in this country. Our early alternating experience was, for well understood reasons, confined to small generators operated on separate circuits. The use of direct-coupled engine-driven alternators did not begin in this country until about 1893, and the cases of parallel operation were quite infrequent until three or four years later. During the years of '95, '96 and '97, I was concerned in the installation of a number of machines of this type which were operated in parallel, but, for various reasons, none of the troubles characteristic to the parallel operation of alternators occurred in these cases, so that up to the year 1898 I had not encountered the problem here discussed and had done nothing towards its solution. In Europe the problem had arisen much earlier, and serious troubles had been encountered which were described in the different electrical journals. These accounts of trouble, combined with our knowledge of phenomena of hunting in synchronous apparatus, led me to be apprehensive about the parallel operation of alternators under certain conditions, before the difficulty was actually encountered.

The first case of trouble which I encountered was in the fall of 1898, when two 800 k. w. 60-cycle alternators operated at 100 r. p. m. from McIntosh and Seymour engines were put into operation in Cleveland. These machines, when thrown into parallel, immediately began to surge so violently as to render service impossible. About the same time we started two 1000 k. w. 60-cycle machines of the same type in Philadelphia and four 1500 k. w. 60-cycle machines at 120 r. p. m. in Boston. In both cases the same trouble appeared that had occurred in Cleveland, except that it was worse in both the latter cases, particularly in the case of Boston, where parallel operation was at first impossible under any condition of load.

I happened to be responsible for the engineering of these three plants, and found myself confronted with a very serious problem. I carefully considered the available European information which bore upon the subject, and found that two remedies for this trouble had been there applied. One of these remedies was described in an article by Mr. Gisbert Kapp which came to my atttention. This article explained that the period of oscillation in relative motion of parallel alternators was govered by two quantities; namely, the electrical synchronizing force, and the weights of the moving systems. Mr. Kapp explained that these quantities could be estimated and compared, and an arrangement could be adopted by which the natural period of oscillation between machines would not conform to the strokes of engine, or would be of such a frequency that trouble was unlikely to result. The other method of cure I found described by M. LeBlanc, who advocated the use of deadeners in the form of windings or attachments to the field structure in which currents would be generated by the shiftings of flux, and which would so serve to consume energy and interpose an electrical friction which must tend to kill the oscillations.

A careful consideration of both these remedies indicated to my mind that neither of them afforded an adequate solution of the difficulty with which we were confronted Special design of dynamos to obtain certain synchronizing effects with certain loads was almost out of the question, since commercial dynamos should be adapted to operation under all conditions, so that the investment in them may not be lost when change of condition is brought about through growth or other circumstance. M. LeBlanc's method was also objectionable, since it introduced devices which must occupy valuable space, and complicate the design of machines, and which must, under operating conditions introduce more or less serious losses. It was furthermore reasoned that a simple deadener could not be complete in its effectiveness since the deadening effect must increase in proportion to the oscillation, and must be very small where the angle of oscillation is slight. It therefore seemed that this disappearing quantity would probably limit the extent of oscillations, but could hardly be expected to entirely prevent them under all conditions. Our subsequent experience showed that both of these methods were sound in theory and practicable within certain limits, but also developed the fact that they could not be depended upon as a basis of commercial work under various conditions.

At the same time that these theories were being considered I started a set of investigations with a view to ascertaining the exact conditions which existed in engine and dynamo while these troubles were occurring. In conducting these investigations, I reasoned that there must be a powerful actuating force employed in keeping these oscillations alive, since the waste of energy incident to their maintenance must necessarily be large, even where no pole-piece attachments or other form of deadeners are used. Theory clearly indicated that the oscillation was a pendulum action, whose period was governed by the weight and by the synchronizing power. I reasoned that this pendulum continued to swing in spite of a heavy friction, and I conducted my investigation with a view to ascertaining the actuating force. I presumed that this actuating force must come from the steam in the engine cylinders, and I had careful sets of indicator cards made showing the impulses under successive strokes and in the different cylinders. The comparison of these indicator cards immediately showed that there was a large irregularity in the delivery of steam to engines, and that the differences ef area in different cards or in cards which should be the same under fixed load were very great. It was further observed that these variations arose from periodic motions of the governor, and that they conformed in period with the swing of the machines, and with the fluctuations of electro-motive force and current.

These facts, which were communicated to me by letter from Cleveland, led me to believe that the cure for the trouble must be sought in a prevention of a rapid periodic motion in the engine governors. I explained this in letters to the engine builders, suggesting to them that retarding dash-pots be used on their governors, which would prevent these sudden motions. The builders of the Cleveland engines, in return, replied that their governors were fitted with dash-pots, and that they were of the best anti-hunting type then known to the art. By such correspondence I soon discovered that the matter was entirely beyond the practical experience of the engine builders, and that we could hardly expect them to afford us a solution of the problem. I then went myself to Philadelphia, where the conditions for experiment were favorable, first communicating my theory in writing to the purchaser and to the engine builder as a matter of record. The governors of engines in Philadelphia were so arranged that dash-pots could be very readily attached to them, which would limit the speed of their motion to any desired degree. Our first experiment was to block the governors positively and run with fixed load. Under this condition, no sign of oscillation appeared. We then operated the engines under various conditions of load and excitation, with and without dash-pots having various degrees of stiffness. These investigations showed that the tendency to oscillation gradually disappeared as the freedom of the governor was limited by the dash-pot. Under certain conditions a small dash-pot effect would kill the oscillation altogether, while under other conditions a stiffer dash-pot would be found necessary. In every case, however, the dash-pot effected improvement, and the cure seemed to be simply a matter of degree. In this particular case, it was found that satisfactory parallel operation under all conditions of service could be obtained with dash-pots which were not so stiff as to materially interfere with the quick action of the engines, and such a cure was adopted, so that the investigations were not carried further in this plant.

From my experience in Philadelphia, however, I reasoned that other cases would arise where such a cure could not be applied, since the dash-pots necessary to afford stability of parallel operation would be too stiff to admit of the proper quick governing of the engines. These anticipations were very soon realized in the operation of the machines above mentioned at Boston. In these machines the oscillating tendency was so strong that they could not keep in step at half load with dash-pots so stiff as to admit dangerous variations of speed with sudden load fluctuations From this experience it was seen that we must find some means of deadening the motions of the governor occasioned by the oscillations, and at the same time we must leave the governor free to move where actual changes of load came upon the machine. A means of accomplishing this result was devised in Cleveland by the combined efforts of Mr. H. W. Buck, my assistant, and Mr. Harte Cook of the McIntosh and Seymour Co. The device is shown in Fig. 1, which shows only one of many forms devised for accomplishing practically the same result. The main piston rod shown in this sketch is connected to the governor weights in such a manner as to be moved directly by them. The space on both sides of the piston and all the port spaces are filled with a heavy grease. By-passes, F, are provided, through which this grease can flow from one side of the piston to the other. Each of these by-passes is actuated by a small piston-valve, C, backed by a spring, G, and provided with a small by-pass, B. The practical effect of this device is that the springs tend always to keep the gates of the main by-passes closed, and that the piston is thus virtually locked until the pressure at one end of it has forced the by-pass valve back. The first motion of the main piston is thus limited by the size of the small by-pass, B, whereas its later motion, after the valve has been forced back, is limited only by the size of the main by-pass, F. It will be readily seen that this dash-pot can be so adjusted that it will act as a temporary lock on the governor mechanism, and that it will release entirely after the tendency to govern has continued for a certain length of time.

Such dash-pots were first applied to the engines above mentioned operated in the plant of the Boston Electric Light Co., and it was found that they afforded a positive and complete cure of the oscillating troubles which had been experienced there. By their use, with proper adjustment, the engines can be operated under all conditions of load, and with any number in parallel, without the slightest indication of the oscillating trouble which was at first so difficult to prevent. In this case the tendency to oscillation was much more positive than in any other which has come to my notice, and the perfect success of the remedy has led me to believe that the method is universally applicable, and that all similar troubles can be cured by its intelligent application.

In order that this form of dash-pot may properly accomplish its functions in the most difficult cases, it must be made strong enough mechanically and hydrostatically to bear, for a time, the entire force imposed by the governor weights in their effort to assume a new position, and the period of such opposition must be such that the dash-pot will not unlock within the time of a single period of oscillation when the machines are operating in parallel. It is also necessary that the dash-pot be kept full of grease, so that there will be no lost motion through air spaces. If the dash-pot falls short in any of these particulars, the remedy which it affords will only be partial, and in difficult cases it may prove inadequate. It is only in certain difficult cases that we need use such complete preventives as were found necessary in Boston.

While discussing this subject, it may be profitable to briefly touch upon a few other facts which have developed in the course of my experience in the parallel operation of alternators. It is popularly supposed that it is necessary to use very heavy fly-wheels in order that alternators may be successfully operated in parallel; it being the custom of some engineers to consider a guarantee of small angular variation as the equivalent to a guarantee for parallel operation. My experience has rather indicated that generators with light fly-wheels are most easy to operate in parallel. The frequency of natural oscillations in such machines is high, and the conditions of engine operation are generally unfavorable to their development. Large fly-wheels are desirable on direct coupled alternators, because a steady frequency is a valuable feature in any system. The requirements of parallel operation, however, are rather unfavorable than otherwise to the use of heavy fly-wheels.

The peculiar periodic action of an engine's governor which I have before described, is not confined entirely to the parallel operation of alternators, but also may occur and cause trouble where a single alternator is operating a load of synchronous apparatus. We may even have alternators which will operate together in parallel, but which will, through periodic action of the governors, give trouble with certain loads of synchronous apparatus. It is thus desirable in all cases to prevent this periodic action of the governors, and by this prevention many troublesome difficulties may be lessened or overcome.

The behavior of all parts of the system while this oscillating trouble occurred in parallel operation was very beautifully illustrated during our experiments in Philadelphia. The shafts of engines were in line, and the relative positions of poles could, at all times, be seen, the poles of one machine appearing to stand still when the machines were in perfect synchronism. The movements of the governor mechanism could also be seen by oscillations of a lever arm which was in the line of vision. Ammeters and voltmeters were also placed in the same line. It was possible at a glance to see the degree of angular displacement of the poles, the degree of motion of the governor, and the fluctuations of the current and voltage. An observation of these conditions showed very clearly the exact character of this phenomenon. It was found that under some conditions the oscillation was an extremely sensitive matter, and had very little power of sustaining itself. A slight change in the field strength of one of the machines would sometimes break it up so that it entirely disappeared, after which the machines might remain steady for some time and then gradually begin to swing again. Under other conditions it was more persistent. Everything indicated, however, that it could not exist for any appreciable period without the actuating force afforded by the irregularity of steam impulses.