GIVE THE OPERATOR A JOB

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The author shows how economies can be secured in electric railway operation by the use of automatic substations. He presents the subject in a very human way and gives tables relative to the saving in energy, the effect upon schedules, a hypothetical case, comparative cost and operating expenses, and finally summarizes the results obtained by the use of manual and automatic control.—Editor.

Many electric railway companies are finding it profitable to employ the otherwise idle time of their substation operators in such ways as either to bring in revenue or at least to reduce expenditure. The picture of the substation man reading a magazine with his feet on the desk is being rapidly "dissolved" into one where the work bench replaces the desk and the man's attention is fixed upon a lathe or upon an armature coil he is repairing. The latter looks more businesslike, to say the least, and certainly is more remunerative to both employer and employee.

The railways can go one step farther. What does the average substation operator do when he works, especially in the interurban substation? He cuts in and out machines at specified times whether there is load or not. He closes the circuit breakers when they open, due to an over zealous motorman trying to make up time. He keeps the substation log, if there is one. He sweeps out the building and blows out the machines—sometimes. Aside from these duties he is a comparatively free man. To be sure, many operators must be baggage and ticket agents, and perform various incidental duties, but they belong to another category.

If these are the chief duties of substation operators, why cannot some scheme be worked out which will mechanically or electrically perform them? Human intelligence is no longer necessary to watch the water tank and start the pump when it becomes empty; a float switch accomplishes this. Neither is constant human effort necessary to weave an intricate design in a fabric; the perforated "card" does this. The starting of the water pump is merely the response to load demand and the weaving of the design is the accomplishment of a purpose through a succession of steps. Until recently railways have found it necessary to employ intelligent substation attendants, but modern ingenuity has developed a means of substation control which renders such intelligence unnecessary.

The way it is done is quite simple. The switches the operator throws by hand are replaced by those electrically operated. The order in which they are closed or opened is determined by a slowly revolving cylinder.

Thus, starting and stopping the apparatus could easily be effected without the attention of the operator. But how about closing the circuit breakers after the motorman has exceeded the acceleration limit? One way is not to let the breakers open; or, rather, not to entirely disconnect the feeder from the bus. A little resistance could be inserted which would limit the accelerating current to a reasonable value. This resistance could be cut out after normal conditions had again been reached.

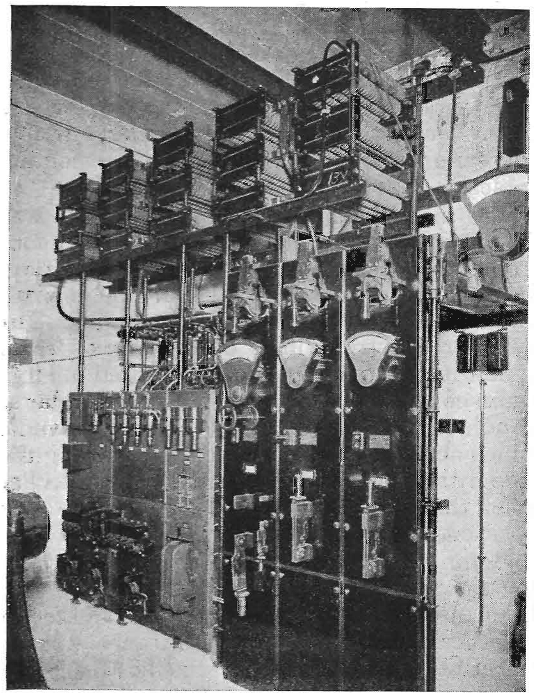


Fig. 1. Automatic Railway Substation. Direct-current Panels and Automatic Equipment which Supersedes Them

Keeping the log has already been reduced to a science by the advent of numerous graphic meters and indicators, while sweeping out the building and blowing out the machines still remain unsolved!

It is not difficult, then, to see how a railway substation can be made to function naturally whether the operator is there or not. Why not take the operator away and put him on the repair or line gang; where possibly he can earn more money and the company save something? This is possible and practical in the automatic railway substation.

Granting the expense of operators can be greatly minimized,—it naturally cannot be entirely eliminated, since the apparatus must be inspected—there is another item of expense which may be reduced—the power bill.

The most economical scheme of operation is to start up the substation when there is a demand for power and to shut it down when this demand disappears. To operate otherwise means a constant waste of energy in heating the machines and churning the air.

If the railroad operates a car-an-hour schedule for twenty out of the twenty-four hours, it is safe to say most of the substations really carry an appreciable load only 50 to 60 per cent of the time. The remaining 40 to 50 per cent of the time they are running light,

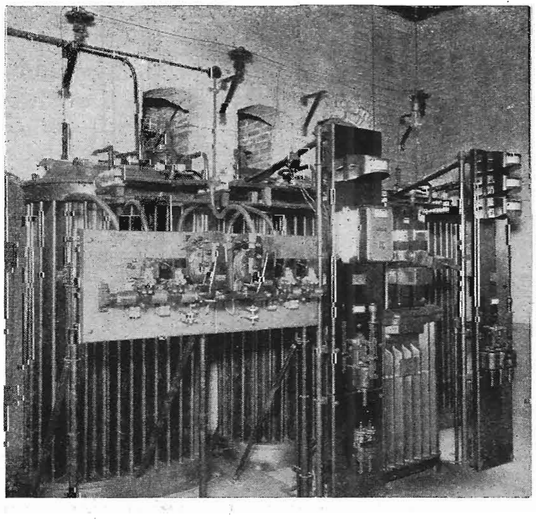


Fig. 2. Automatic Railway Substation. Alternating-current Starting and Running Contactor Panel. Superseded Hand-operated Panels to the Right

or nearly so. Taking the light load losses at 4 per cent. a 500-kw. substation would waste 20 kw. for eight or ten hours, or 160 to 200 kw-hr. per day; or further $292.00 to $365.00 per year at one half a cent per kw-hr. This is, say roughly, one third the yearly wage of an operator. Hence it appears that placing a man in a substation is about as inefficient a way to utilize him as could be imagined.

We have hinted at the means provided to operate a substation automatically—the electrically controlled switches and the revolving

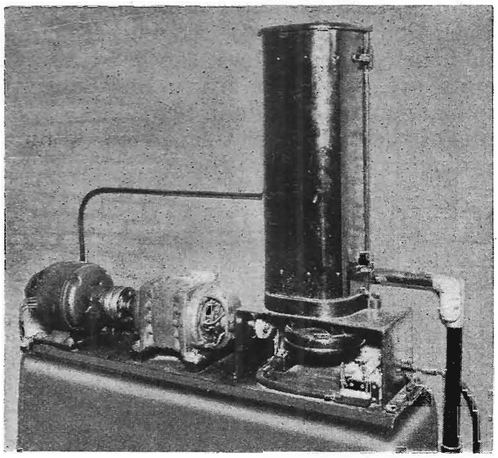


Fig. 3. Motor-driven Drum Controller with Polarizing Generator Direct Connected

cylinder. The demand for the power is indicated by a drop in trolley voltage. The contact-making voltmeter may be used to start the cylinder moving. When the demand ceases, the substation delivers little or no current and a current relay will register the fact, disconnecting the machine from the system. It then remains but to correlate and supplement these devices by the use of contactors and other relays to obtain a practical, operative equipment.

Figs. 1 and 2 show clearly how the equipment looks when placed beside an old switchboard manually operated, while Fig. 3 pictures the revolving cylinder driven by a small motor. The resistance which is inserted in circuit during a heavy draft of current appears in the upper part of Fig. 1.

It must be expected that numerous difficulties have to be overcome. The first one is the fixing of the proper polarity if a synchronous converter is started from the alternating-current side. The small direct-current generator shown in Fig. 3 does this when it is connected to the converter field at the proper time. Another difficulty presents itself if we imagine the trolley wire or third rail grounds throwing a heavy overload on the machine. The resistances and several thermostats avert the danger; the resistances limiting the output, and the thermostats shutting down the machine if the temperature becomes dangerous. Other difficulties are obviated in equally efficacious ways.

The complete wiring diagram for a certain installation is presented in Fig. 4 and the details of operation may be studied thereform. To simplify matters and to give the sequence of operation at a glance, reference to Fig. 5 should be made. Here the load-carrying circuits are shown in heavy lines and the principal control circuits in light lines. A dot in one of the squares of the tabulation under the diagram indicates the correspondingly numbered device is closed at that point in the sequence. The complete wiring diagram shows various interlocking circuits which prevent false operations should any device fail to function properly.

A question frequently asked is: Does not the substation shut down every time the motorman throws off the power? No, because relay No. 3 has a time delay which keeps it closed as long as five minutes, if necessary, after it is de-energized. Another question: Is not a large quantity of energy lost in the limiting resistance? No, to this also. Experience has shown that as much as 4 kw-hr. is "wasted" per day in a 300-kw. equipment. And at that, it really is not "wasted" since experience has also shown that the cushioning effect of this resistance has not only reduced the wear and tear on the substation apparatus, but it has practically eliminated flashovers of the car motors, thus materially decreasing their maintenance.

Some very interesting problems present themselves for solution where a railway is operated automatically. The economical spacing of substations, their capacity, and the amount of feeder copper installed, all hinge upon the production of a nice balance between first costs and between annual operating expenses. Assuming given conditions of traffic, the greatest dividends are possible on the railroad costing the least to install and operating at the least expense. Now, since the automatic substation can operate trains on the same schedule with less energy than one manually controlled, and since the attendance expense account is greatly reduced, it is evident new balances can be struck and these bear investigating.

It is a fact that even manually operated substations are cheaper than the feeder copper between them; that is, down to a point where the number of substations per mile of track is greater than present practice indicates. It is

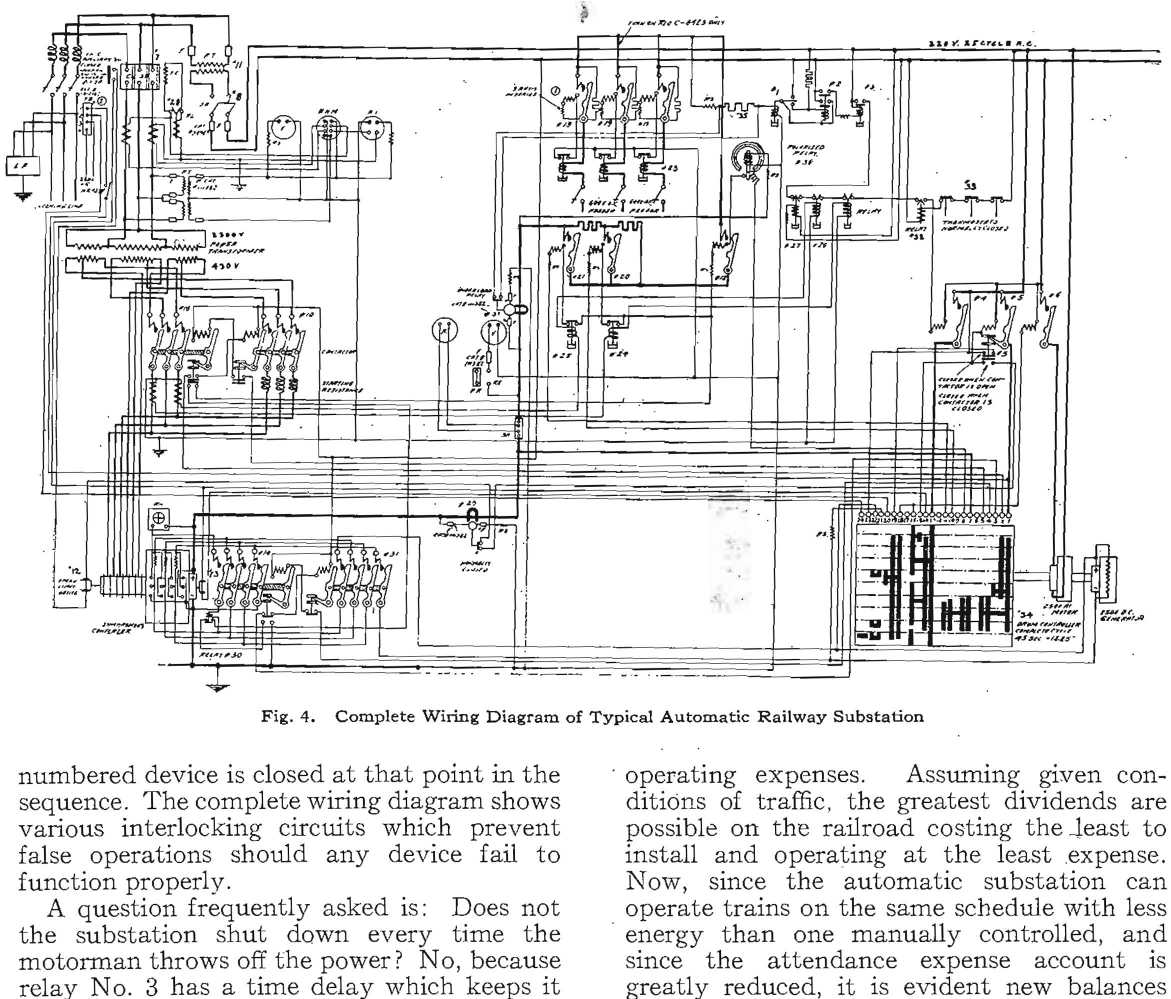
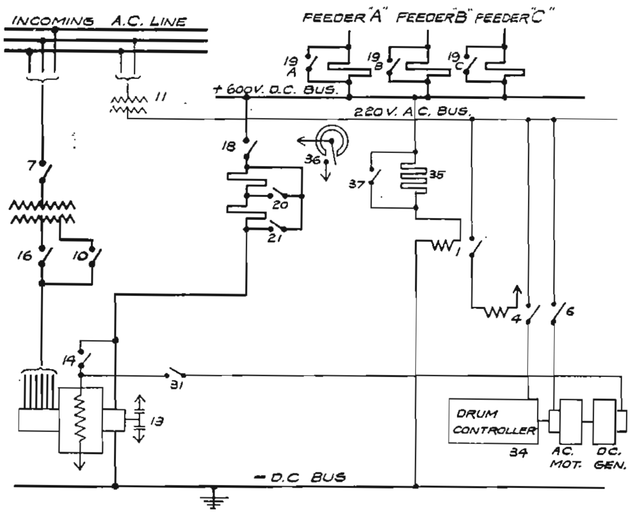


Fig. 4. Complete Wiring Diagram of Typical Automatic Railway Substation

the expense of operating them that keeps them at a respectable distance. With a lower operating cost and smaller power bill, it seems that a little feeder copper might be saved and possibly more substations installed with a net reduction in first cost, or at least a reduction in operating expense. Some roads already in existence have found it convenient to cash in a quantity of feeder metal and have enough money left after buying automatic equipment to make some needed improvements. With attendantless substations in the field, old ideas regarding electric railroading must be modified to meet the new situation.

A few figures will show the general tendency toward a reduction in annual expenditures. Each individual road must be judged upon its own merits, but the figures given below will serve as a guide, and modifications can be made applicable to specific cases. It goes without saying that the expense of attendants can be materially decreased, but is there a saving in power worth mentioning? To show that there is, Table I has been prepared. This estimate is based upon the car schedules shown in Fig. 6.

Before leaving Fig. 6 some interesting things should be noticed. One train sheet shows 120-minute headways and the other 60-minute. Each is divided into three schedules of different layovers. The time each sub-



	SEQUENCE	1	4	6	7	10	13	14	16	18	19 A	19 B	19 C	20	21	31	36	37	REMARKS
1	SHUT DOWN										•	•	•					•	CONTROLLER "OFF"
2	LOW D.C. VOLTAGE	•	•	•							•	•	•					•	" STARTS
3	1ST CONTROLLER POSITION	•	•	•	•						•	•	•					•	OIL SWITCH CLOSED
4	2ND " "	•	•	•	•	•					•	•	•					•	STARTING TAP
5	3RD " "	•	•	•	•	•	•				•	•	•					•	SYNCHRONOUS SPEED
6	4TH " "	•	•	•	•	•	•				•	•	•			•	•	•	POLARITY FIXED
7	5TH " "	•	•	•	•		•	•	•		•	•	•				•	•	FULL VOLTS-SELF EXCITED
8	6TH " "	•	•	•	•		•	•	•	•	•	•	•				•		ALL RESISTANCE IN
9	7TH " "	•	•	•	•		•	•	•	•	•	•	•	•			•		PART RESISTANCE OUT
10	8TH " "	•	•	•	•		•	•	•	•	•	•	•	•	•		•		ALL RESISTANCE OUT
11	9TH " "	•	•		•		•	•	•	•	•	•	•	•	•		•		CONTROLLER STOPS "RUN"
12	LIGHT OVERLOAD FEEDER "A"	•	•		•		•	•	•	•		•	•	•	•		•		19B, OR 19C, OPEN ON
13	MEDIUM " " "	•	•		•		•	•	•	•		•	•	•			•		FEEDERS "B" OR "C"
14	HEAVY " " "	•	•		•		•	•	•	•		•	•				•		CORRESPONDINGLY
15	UNDER LOAD			•	•		•				•	•	•				•	•	CONTROLLER STARTS
18	SHUT DOWN										•	•	•					•	" STOPS "OFF"

Fig. 5. Simplified Wiring Diagram and Table showing Sequence of Operations

TABLE I

AUTOMATIC CONTROL

Energy Economies

Headway between cars		120 min.	60 min.
Length of road	mi.	50	50
Schedule speed	m.p.h.	25	25
Weight of cars	tons	30	30
Number of stops per mile		0.5	0.5
Capacity of substation converters	kw.	300	300
Length of operating day	hr.	18	18
Total car miles per day		900	1800
Energy consumption per car mile	kw-hr.	1.7	1.7
Total energy per day at cars	kw-hr.	1530	3060
Total energy per day high-tension side substation	kw-hr.	1860	3720
Total substation hours possible (5 substations)	hr.	90	90
Total substation hours actual running	hr.	30	52
Total time substations are not running	hr.	60	38
Running light losses per substation	kw.	15	15
Energy saved per day, automatic operation	kw-hr.	900	570
Energy saved per year, automatic operation	kw-hr.	328500	208000
Total energy per day, manual operation	kw-hr.	2760	4290
Value of energy saved per year at ½ cent per kw-hr.		$1642	$1040
Energy saved, automatic operation		32.5 per cent	13.3 per cent

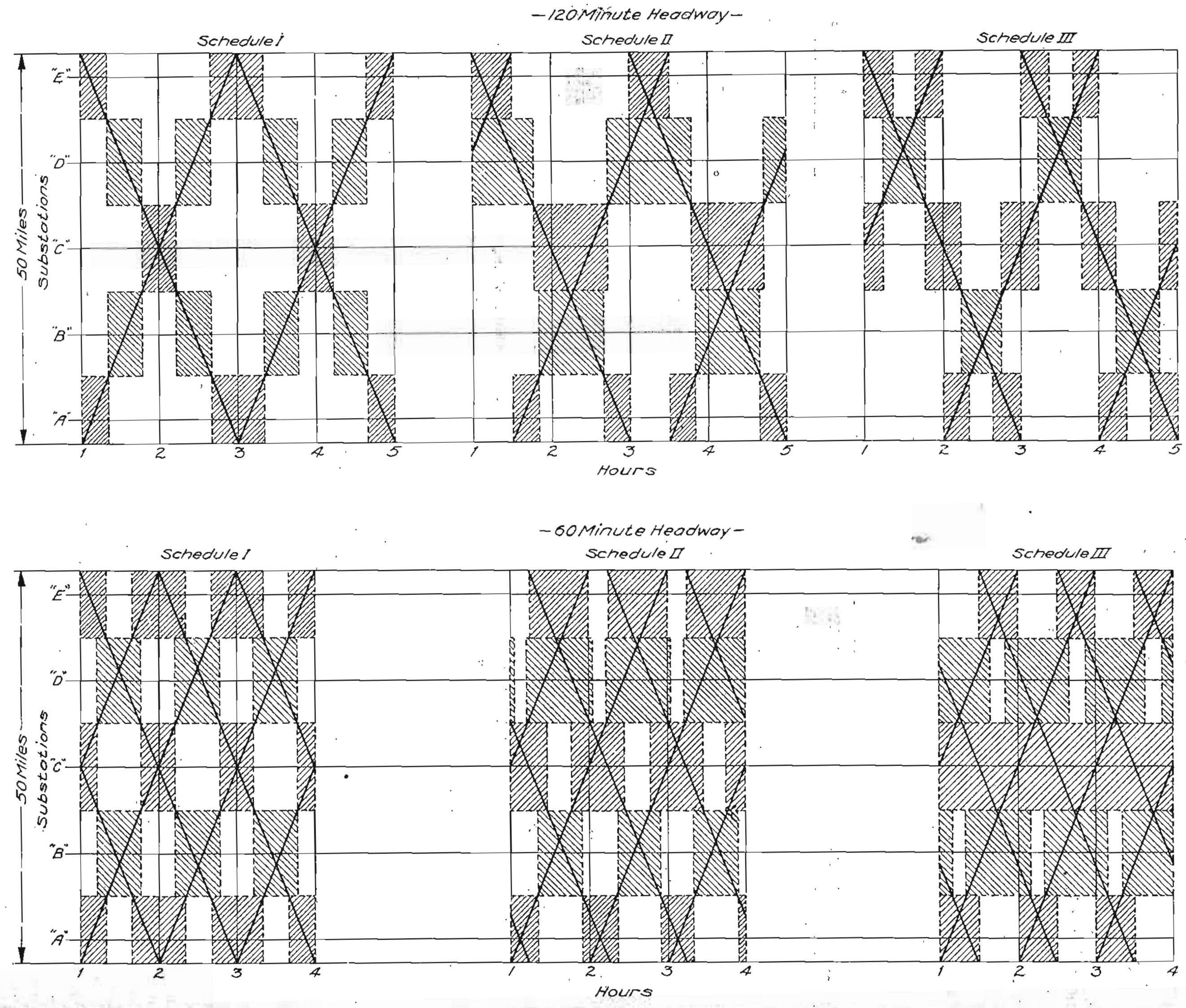


Fig. 6. Train Sheet Showing the Effect of Schedule upon Time of Substation Operation

station carries more than one half the car load is indicated by the shaded portions. If the substations operate automatically these shaded portions indicate when the substations are running. The rest of the time they are shut down. This forms a very convenient method of determining the number of hours per day the running-light losses of a substation could be eliminated by automatic operation. From these train sheets Table II can be made. The curious point to be noticed is that for 120-minute headways more power can be saved with a layover of 60 minutes, and that for 60-minute headways more power can be saved with no layovers. Fortunately enough too, it will be observed in each case that conditions for minimum time of running correspond to maximum efficiency conditions on the substations. In Schedule I of 120-minute headways, only one substation out of the five carries two cars at a time, while Schedule III shows two of the substations so loaded. Again, in Schedule I of 60-minute headways three substations carry two cars each, while with any other arrangement of cars circumstances are not so favorable. The railway efficiency expert may find something of interest here, and raise the all day efficiency of even manually operated substations.

Returning to Table I, it is seen an energy saving of over 30 per cent is possible on roads operating cars every two hours, and a saving of over 10 per cent for cars one hour apart. To be sure these estimates are based upon hypothetical car services, but where a "paper" saving as high as that indicated is possible the means of attaining it should be seriously considered.

It is to be expected that the more infrequent the car service the greater the energy saving, but it is on the railways having just such a service that the power bill is the largest in proportion to the total operating expenses. The same is true with regard to the item of substation attendance. The interurban road running few cars per day presents, then, the immediate future for the automatic substation.

To make the case complete, further evidence should be introduced. Let us assume an electric railway already running. The general specifications appear in Table III. In order to bring out the effect of the size of feeder, two cases are assumed, one where a 4/0 feeder reinforces the trolley conductor, and the other where a 500,000 c.m. feeder is used. The latter is evidently over feedered.

The items of cost and expense appear in Table IV and it will be noted two methods of application of the automatic feature are included. In either case, and either method, a distinct saving accrues, the relative amounts being given in the Summary, Table V.

The tabulations bring out a valuable point; viz., the greatest economy in operation sometimes is attained by merely converting the substations already in operation, and other times by increasing the number of substations. It depends upon conditions. Naturally a road that is overfeedered would show a large saving, but it would do this much under manual operation.

Taxes and the cost of land have not been included in these calculations on account of their varying values. To make the comparison complete these items should, of course, be considered.

TABLE II

EFFECT OF SCHEDULE UPON TIME OF AUTOMATIC SUBSTATION OPERATION

Minutes of Substation Operation per Hour

	Substation	A	B	C	D	E	Total Substation Minutes Per Hour
	Headway 120 Minutes						
Schedule	I—No layovers	20	27	13	27	20	107
	II—30- and 90-minute layovers	20	25	28	32	15	120
	III—60-minute layovers	20	18	25	17	20	100
	Headway 60 Minutes						
Schedule	I—No layovers	40	35	26	35	40	175
	II—15- and 45-minute layovers	25	35	40	50	45	195
	III—30-minute layovers	30	50	60	50	30	220

Thus far nothing has been said about the broad question of reliability of the automatic apparatus. This subject will bear thought, and since it defies accurate numerical calculation, making capitalization difficult if not impossible, its value can only be judged by argument.

In the manually controlled substation the apparatus and its proper operation is dependent upon the human element and its vagarious efficiency. The exceptional operator uses such keen judgment and conducts his duties with such accuracy and dispatch that he soon gets his job, and we are therefore not concerned about him in this discussion. But the average operator of the desk and magazine type mentioned early in this article must receive our attention. The monotony of his work soon hardens him to a state of semi-coma. If he gets his machines on the line at specified times (whether or not the load conditions require them) and keeps his breakers closed, the major portion of his day's work is done. It is only in times of stress when things do not run smoothly that he is called upon to exhibit quick and accurate judgment. Many stories have been told—some not without their humorous side—of operators performing fearful and wonderful feats during times of trouble and excitement; feats for which the men themselves would truthfully disclaim credit and vigorously deny having done. Mr. E. E. F. Creighton in Trans. A.I.E.E. for 1912 discusses several such performances.

Knowing these conditions, the railroads must nevertheless place their apparatus under such circumstances. It is not to speak disparagingly of the operators that this statement is made—they are human.

Fallibility is not unknown in electrical or mechanical devices, and although the scheme of automatic operation includes several protective features, and the circuits are carefully interlocked, yet it may be possible to imagine a combination of conditions which might result in a traffic delay. But such a combination is improbable. One thing is certain; that as long as the devices are kept in working order, events in operation can only take place in one particular (and proper) sequence no matter how rapidly the conditions may change. And furthermore, this sequence will take place with the same speed and precision regardless of the stress of circumstances.

TABLE III

MANUAL CONTROL

Data for Assumed Road

Physical Characteristics		
Length of road	mi.	50
Schedule speed	m.p.h.	25
Weight of cars	tons	30
Headway between cars	min.	120
Number of stops per mile		0.5
Number of substations		5
Capacity of substation converters	kw.	300
Length of operating day	hr.	18
Car miles per day		900
Energy consumption per car mile	kw-hr.	1.7
Total energy per day at cars	kw-hr.	1530
Total energy per day high-tension side substation	kw-hr.	1860

Cost and Operating Expenses

	Normal Feeder	Over Feedered
Size of feeder (copper) 44 miles	4/0	500,000
Original cost of substations at $40.00	$60,000	$60,000
Original cost of feeder installed	41,000	82,000
Total cost	101,000	142,000
Maintenance of substations at $200.00	1,000	1,000
Substation attendance at $75.00	9,000	9,000
Interest and depreciation at 10 per cent	10,100	14,200
Power at ½ cent per kw-hr.	5,037	4,770
Total operating expenses (approximate)	25,000	29,000

The same cannot be said under human control.

All the relays and contactors making up the automatic equipment are devices which have been standard for a number of years and used extensively in power stations and industrial applications. They have all proven their ability to function successfully. It is only their application to railway work which is novel. The automatic substation still retains the usual lightning protection. If a lightning stroke were severe enough to damage the apparatus, it would do so whether an attendant were present or not. There is a bare possibility that on systems prone to severe short circuits on the direct-current side, the current on this side would rise so rapidly that the machine would be subject to momentary danger until the protective resistance was inserted. In such cases complete protection could be provided by the use of a quick opening switch or contactor, or by the use of a small amount of inductance in the direct-current circuit.

With all its trimmings the automatic substation is less complicated than the multiple unit car it feeds. The service it gives equals in continuity its manual predecessor.

We have already seen the application of automatic substations as a means of saving energy and diminishing the expense of operators. There are many other ways that losses may be saved or inordinate financial outlays averted. A few may be enumerated.

There are roads still running on the now obsolete and highly inefficient booster scheme. The amount of feeder conductor which can be turned into cash capital is something

TABLE IV

AUTOMATIC CONTROL

Comparative Costs and Operating Expenses, on Basis of: First, using Present Number of Substations; and, Second, Using More Substations and Taking Down the Feeder

	CASE I NORMAL FEEDER		CASE II OVER FEEDERED	
Number of substations	5	9	5	9
Size of feeder	4/0	None	500,000	None
Weight of feeder copper	150,000	0	356,000	0
Cost of conversion of present substations	$16,500	$16,500	$16,500	$16,500
Cost of new substations (200 kw.) at $46.00	......	36,800	......	36,800
Total cost	16,500	53,300	16,500	53,300
Credit for feeder removed at 25 cents	......	37,500	......	89,000
Approximate initial investment	16,500	16,000	16,500	*
Maintenance of substations	1,000	1,800	1,000	1,800
Substation inspectors at $100	2,400	3,600	2,400	3,600
Interest and depreciation at 10 per cent	11,800	11,800	15,900	7,000
Power at ½ cent per kw-hr. (1860 kw-hr. per day)	3,400	3,400	3,400	3,400
Total operating expense (approximate)	19,000	21,000	23,000	16,000

* There is a balance of $35,700.00 after paying for all the automatic equipment. This is applied as a credit to the original cost of the installation and the interest and depreciation is based upon the new cost figure.

TABLE V

AUTOMATIC *VERSUS* MANUAL CONTROL

Summary

	MANUAL CONTROL		AUTOMATIC CONTROL			
	Orginial		Case I Normal Feeder		Case II Over Feedered	
Size of feeder—44 miles	4/0	500,000	4/0	None	500,000	None
Number of substations	5	5	5	9	5	9
Initial cost	$101,000	$142,000	$117,500	$117,000	$158,500	$106,300
Annual operating expenses	25,000	29,000	19,000	21,000	23,000	16,000
Saving in operating expenses	.....	.....	6,000	4,000	6,000	13,000
Years to pay for auto. equip.	.....	.....	2 to 3	4 to 5	2 to 3	Credit
Saving in operating exp. per mi.	.....	.....	$120	$80	$120	$260
Saving in operating expense	.....	.....	24 per cent	16 per cent	24 per cent	52 per cent

enormous, to say nothing of the improved voltage conditions at the cars, with consequent improvement of schedule.

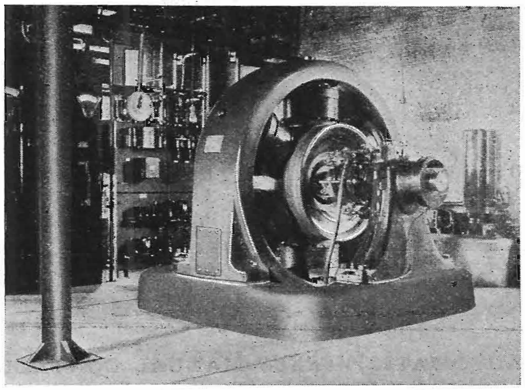
Should the unexpected happen and the service on the railway increase after the initial installation, the most economical remedy would be the automatic substation, one placed between each present substation. It is possible these could have units smaller in capacity than the original.

Centers of excursion traffic present admirable locations. Portable substations to bring the power supply near temporary loads such as gravel pits, road-side quarries, etc., are now more practical than ever, since they can be made automatic and operate only when the trains move.

A feature of the load limiting resistance which should not be overlooked is its value in reducing peak demands on the system. A power contract placed on a peak demand basis can now be rewritten to the advantage of the railway.

Finally, the building which houses an automatic substation can be compact and reasonably constructed. Living quarters, so frequently necessary, are no longer required. Provision for heating and the attendant fuel expense can be reduced to nothing. Windows may be small and high.

Much has been said so far of what *might* be done, what savings *might* be made. Has anything actually been done to warrant these statements? Yes. Four substations are now in regular operation and before this article is read six or seven more will have been started. The scheme therefore is practical and it works. The manufacturers are building six more railway equipments to say nothing of three others to control waterwheel generators and one to control a synchronous condenser. These last, by the way, indicate that the field of application is not limited to railways, but this is another story. Accurate figures of savings are not yet available although one road claims economy of energy considerably beyond that estimated in the accompanying tabulations. All of which goes to show several of the railway companies—and they are not all confined to the interurban field—see the light. They give the operator a job.



Automatic Railway Substation