LOAD DISPATCHING

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INTRODUCTION

As system loads grew, more generators had to be added, and power stations with several generators became common. As systems grew, several generating stations were connected together to share in supplying loads, and in recent years large systems have been interconnected into so-called superpower systems for exchange of energy and for emergency service. For best economy and reliability it is imperative that the operation of each of the individual units of such a system be under the direction of one central office or directing authority. This central office is a branch of the System Operating Department and is known as the Load Dispatching Office which is under the direction of the Chief Dispatcher. In large systems it is advisable to have district offices, all of which report to the Chief Dispatcher's office, from where all important orders originate. The duties of the Dispatcher's Office may be summarized under two heads: (a) to protect the service, (b) to produce service at minimum cost.

The first item includes taking care of all emergencies during lightning storms or accidents, maintaining voltage and frequency on all lines, and in general supplying the customers with continuous and reliable service. Large load centers should be supplied from several directions and, in case of trouble in any one section, it is the load

dispatcher who must change the routing of power through undamaged circuits in order to limit the outage of service to a minimum. This method of operating requires an ability to parallel alternating current generators and systems in order that there may be continuity of service and elasticity of supply.

The second duty of the dispatcher is to distribute the load between the several plants under his direction in such a manner that minimum cost of production is realized. This requires a complete knowledge of the weather conditions which influence hydro plants, fuel economy of different steam plants, and advisability of accepting purchased power.

PARALLEL OPERATION

In a central station three things make necessary parallel operation of alternators:

1. Limitation in available size of units.
2. Economy in plant operation under variable load.
3. Continuity of service.

Since there is a limit to the capacity of an alternator, a large system must use several units in parallel or compound machines to carry the load.

The load on a plant usually varies through wide ranges and, as a machine operates at maximum efficiency at full load, it is economical to have several machines available in a plant. Parallel operation also makes it possible for machines of different makes and ratings to be used on the bus to carry the load so that economy is obtained by being able to add capacity to a plant with little change in plant installation.

Continuity of service can be more readily maintained in the event of a failure in any alternator because another can be put in parallel on the bus.

Before connecting an alternator in parallel to a bus or circuit which is already energized from another source, it is necessary, in order to prevent excessive and possibly disastrous current flow, that the alternating voltage across each phase of the alternator be equal at each instant

to the alternating voltage across the corresponding phase of the bus. To meet this condition, the alternator must fulfill the following conditions:

1. Must have the same sequence as the bus.
2. Must have the same voltage as the bus at the point of paralleling.
3. Must have the same frequency as the bus.
4. Must have the same phase voltage with respect to the bus load, but in phase opposition with respect to other alternators on the bus.

The first of the above conditions is determined by "phasing out" the alternator once for all when it is first installed. Phasing out consists of testing and connecting the leads so that the phase sequence or sequence of positive peak voltages in the various phases of the alternator corresponds to that of the bus. The last three conditions are determined by "synchronizing" the alternator every time it is connected to the bus. Synchronizing consists of adjusting the voltage and frequency of the alternator to equal that of the bus, and closing the breaker at the instant the machine is in phase with the bus. The proper time to close the switch on the incoming machine can be indicated by synchronizing lamps or better by some form of synchroscope.

If two alternators are operating at the same frequency and are in phase, but are not adjusted to give the

same terminal voltage, there will be a difference of the two alternator voltages, which will cause a current to circulate between the two machines. Since the resistance of alternators is very small compared to their reactance, the circulating current will be

$$I = \frac{E}{X_A + X_B}$$

where I = the circulating current in amperes,

E = the resultant voltage causing current I to flow,

X_A and X_B = reactances of the alternators.

It is true that the circulating current will lag one alternator voltage and lead the other alternator voltage by 90 electrical degrees. Therefore, this current will demagnetize the field of the alternator of lower voltage, thereby making the terminal voltages of the two machines equal.

There are three operating variables which can be studied with respect to the parallel operation of alternators:

1. Excitation of each machine.
2. Turbine governor control on each machine.
3. Load changes.

The excitation of each machine controls its internal induced voltage and power factor and influences the bus voltage. It does not control the portion of the bus load shared by the alternator to any degree unless there is a large impedance between the parallel units. The governor

control on the turbine permits remote control of the portion of the bus load carried by each machine and maintains the system frequency. A secondary effect is to insure stability in parallel operation through the fact that the speed tends to decrease as the load increases.

Changes in the load influence the system power factor, frequency and bus voltage. A decrease in the field current of an alternator operating in parallel with other alternators makes a lagging power factor, and an increase in its field current makes a leading power factor.

The fact that a synchronous motor can be made to draw either a leading or lagging current by merely adjusting its field excitation constitutes one of the most valuable features of the synchronous motor, for it may be utilized to correct the power factor of a transmission or distribution system and to hold it at any desired value within the ability of the motor to absorb or supply reactive power.

Suppose, for example, that a distribution system is supplying power to a heavily inductive load at a power factor of 60 per cent. For each ampere of current taken by the load, 0.6 ampere represents active power supplied, while 0.8 ampere represents reactive power. The quadrature current, though it does no useful work in carrying the load, is nevertheless responsible for ohmic (I^2R) loss just as effectively as though it were truly useful, so that in this example the total ohmic loss is greater than it

would be if the quadrature (wattless) current were absent in the ratio $(1)^2/(0.6)^2 = 2.78$. The gain in efficiency through the suppression or neutralization of the quadrature current is therefore obvious. Another advantage accrues from its neutralization because of the better voltage regulation of the generators that supply the load; and still another for the reason that when the generating and distributing equipment is relieved of the quadrature current, there is released for other service that portion of the system capacity which would otherwise be unavailable because of the temperature rise due to the useless quadrature current. Then it is evident that if a synchronous motor were placed at the center of the distribution of the load, its field could be so overexcited as to cause it to draw a leading current with a quadrature component equal and opposite to that required by the inductive load, and so raise the power factor of the load as a whole to unity; by still further increasing the excitation the resultant power factor may correspond to a net leading current, thereby raising the terminal voltage sufficiently to compensate (or to overcompensate) the line drop. Then briefly summed up, the synchronous motor used in the manner described may be considered to generate a quadrature current sufficient to supply the lagging quadrature component demanded by the load. A synchronous motor used for this purpose is called a synchronous condenser.

As another example, consider a generating plant supplying a distribution system over a long transmission line. Such a line may have such large capacitance that the charging current may be a considerable percentage of the current-carrying capacity of the generators and transmission line. In that case a synchronous machine operated with underexcited field may be made to draw a lagging current sufficient to compensate the condensive effect of the transmission line, and the synchronous machine used in this way is called a synchronous reactor. There are cases where one of the spare generators in a power plant is "floated" on the line, running idly as a synchronous motor with only the friction load of its prime mover as mechanical load, for the purpose of relieving the other generators of the capacitance effect of a lightly loaded feeder.

A synchronous motor used for a power factor correction may, of course, carry a mechanical load at the same time. In the general case, the problem that arises is to determine the rating of a synchronous motor, which, when carrying a definite load of its own, and when operated in parallel with a load of given magnitude and power factor, will adjust the power factor of the combined load to an assigned percentage.

Similarly, a synchronous generator may deliver a power load and also act as a synchronous condenser or reactor. For example, consider two units operating in

parallel delivering a load of power factor angle θ_L, Fig. 1. Assume that the two machines are identical and that the load is divided equally between them, such that $I_{A1} = I_{B1}$ and $I_L = 2\ I_{A1} = 2\ I_{B1}$, where I_{A1} and I_{B1} are the currents delivered by generators A and B respectively. Since the machines are identical, the terminal voltages V_A and V_B must be the same and the induced voltages E_{A1} and E_{B1} are equal and opposite because of equal excitation. Under such conditions there will obviously be no circulating current between the machines. In ordinary commercial use, at least one of the generators will be equipped with a voltage regulator so that

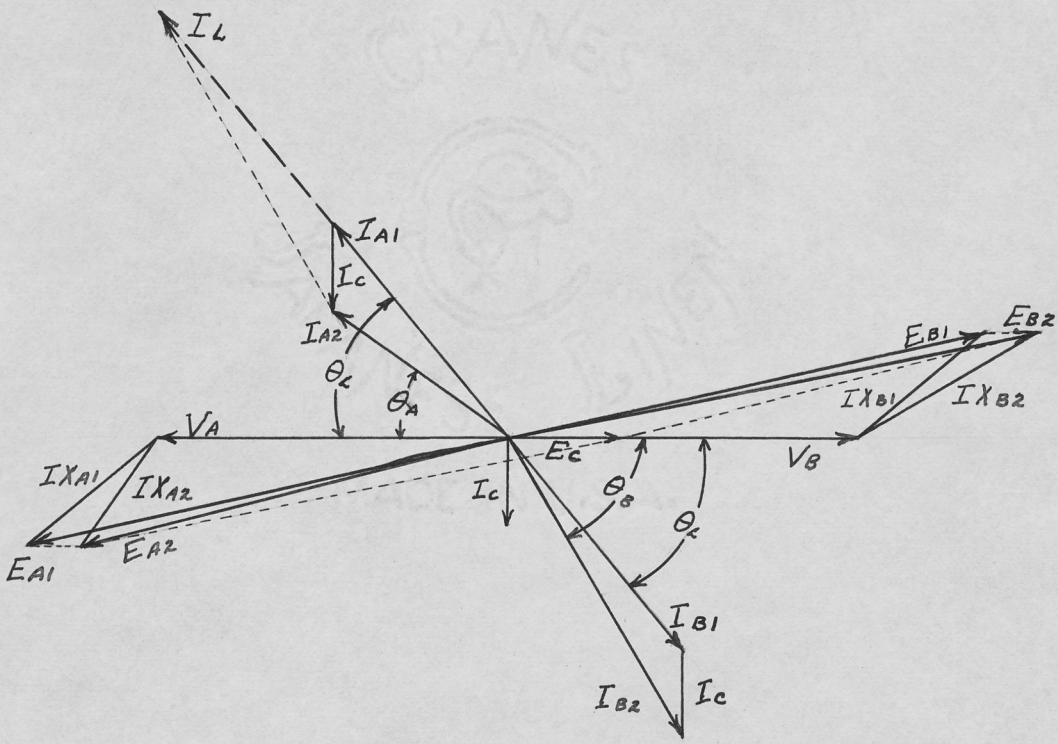


Fig. 1

a constant terminal voltage is maintained. Therefore, to obtain results such as an actual installation would produce, let us assume a voltage regulator on machine B such that its terminal voltage V_B will remain constant. If the load is constant and the governors on the prime movers are set so that each generator will maintain its share of the power load, Figure 1 shows that:

$$P_L = V\ I_L\ \text{Cos}\ \theta_L$$

$$P_A = V\ I_{A1}\ \text{Cos}\ \theta_L$$

$$P_B = V\ I_{B1}\ \text{Cos}\ \theta_L$$

$$P_L = P_A + P_B$$

Then if the excitation of machine A is decreased there will be a decrease in its induced voltage from E_{A1} to E_{A2}. However, machine A cannot deliver any less power, therefore, the decrease in reactance drop must be due to a quadrature component of current I_C. Thus machine A will have a current of:

$$I_{A2} = I_{A1} + I_C \quad .$$

Since the load power factor is unchanged, the current I_C cannot flow to the load, but must circulate through machine B. Then the current in machine B becomes:

$$I_{B2} = I_{B1} + I_C \quad .$$

If the terminal voltage V_A remains constant, the induced voltage will become E_{A2}. The resultant voltage acting around the closed circuit of the two armatures is:

$$E_C = E_{B2} + E_{A2} \quad .$$

Voltage E_C will be in phase with V_B and the current I_C will lag the voltage E_C by 90 degrees, since the armatures are assumed to have no resistance.

From the foregoing discussion, it is obvious that by adjusting the excitation of machine A, the angle Θ_A may be made equal to zero while Θ_B increases considerable. This substantiates the previous statement that the amount of power delivered is not changed by changing the excitation of amachine but only controls the power factor of the units. By this method it is possible to make some machines of a large system carry unity power factor loads while other machines can be made to carry all the reactive current. Also it shows that the energy component of the current is not decreased even though the quadrature component is increased, which verifies the statement that a synchronous generator may deliver a power load at the same time it is acting as a synchronous condenser or reactor.

PRIME MOVER CHARACTERISTICS

It might at first be supposed, by analogy with the case of d.c. generators in parallel, that an alternator operating in parallel with others could be made to carry more or less of the total load by adjusting its field excitation. But when it is recalled that the frequency of a large system is fixed within very narrow limits, it becomes clear that the speed of any individual generating unit must remain constant except for the momentary acceleration or retardation which accompanies hunting, which, when it occurs, gives rise to the circulating current and the automatic tendency toward restoration of the initial steady conditions. The electrical power output of a generator cannot be greater than the difference between the mechanical power input and its own internal losses, so that in general it is only possible to vary the output by varying the input. This means that the division of load between alternators in parallel can be controlled only by adjusting the input to the prime movers, that is, by manipulating the valves controlling the supply of steam to a turbo-alternator or of water to a hydraulic unit. It follows from this discussion that the division of load between alternators in parallel depends almost entirely upon the valve setting of its prime mover, which in turn depends upon the setting of its governor mechanism.

The speed load characteristic of the prime mover of a generator must be a drooping curve, in order that its operation may be stable: for unless the speed drops as the load increases, any increase of load would be accompanied by an increased speed, which would mean a further increase in load until the machine has taken the entire load from those with which it is in parallel, after which it would tend to run away. The governors commonly used on the prime movers operate on the centrifugal principle, the momentary drop in speed caused by an increase of load being utilized to make them operate the valve mechanism: such governors therefore automatically impart a drooping-speed characteristic. and the design is such that there is ordinarily a difference of 3 to 4 per cent. in speed between no load and full load. Usually the curve showing the relation between the average speed and the load is very nearly a straight line within the limits of normal operation.

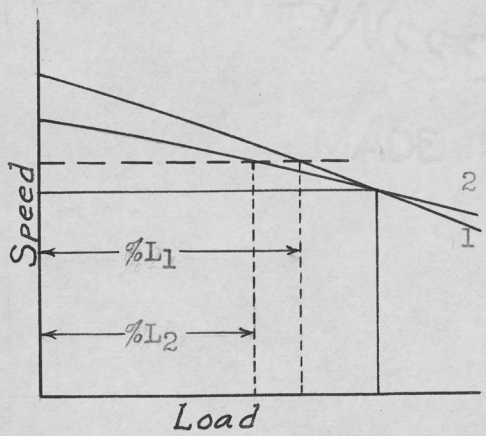


Fig. 2

If two generating units connected in parallel have dissimilar speed-load characteristics, as indicated by curves 1 and 2, Figure 2, they will divide the load in proportion to their ratings only at the particular speed at which their characteristics inter-

sect each other. At any other speed the division of load will depart from this proportion. If the division of load is to remain the same at all loads without the need for special adjustments, both machines must have identical speed-load characteristics. However. it is quite difficult to have two machines with identical speed-load characteristics.

The speed-load characteristics of the prime movers should have considerable droop. Too flat characteristics will exaggerate the effect of any slight differences which may exist between the slopes of the characteristics. Perfectly flat characteristics would produce unstable operating conditions. If the characteristics of the prime movers do not have the same droop,an effect such as shown in Figure 3, will be obtained. When it is desired to make No.2 increase its load, the tension of its governor spring is increased. This will raise the speed-load characteristic nearly parallel to itself to some new position such as is shown by the dotted line. As the engine must still run at the same speed, generator No. 2 now must carry more load. In the case shown, it will carry the same load as the other generator.

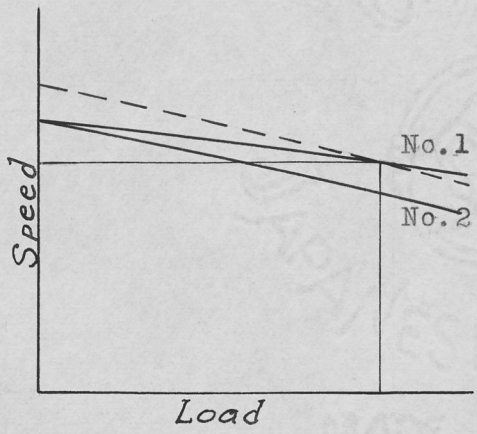


Fig. 3

SPARE GENERATING CAPACITY

The individual power plants play an important role in the system whether it be a small, self-contained system or a link in an interconnected network of various systems. For any particular development, the generating units in that area are depended upon to supply most of the demanded load. When emergencies arise, it may not be possible for any one particular unit to cope with the situation. Therefore, it is almost imperative that each generating station have some stand-by units. To furnish supplementary or auxiliary power to the system either a steam unit or hydro unit is adequate. Judgment should be exercised when carrying a unit as a stand-by because of the variable characteristics of the two types and the variable nature of emergencies. For example, a stand-by hydro unit on the same water source would not be of much advantage during a period of water scarcity. For such an emergency, therefore, some form of steam or fuel burning unit is desirable and necessary. On the other hand, a sudden break-down of one of the load carrying units could quickly be supplemented by a hydro unit without a very long interruption. In fact, it is more desirable to have a hydro generating unit for sudden interruptions than to have a steam unit, because of the length of time required to get the unit into operation. A hydro-electric plant of three units can be put into operation in an emergency, from no-

load (stationary) to full capacity, in less than four minutes, while a steam plant, even with the boilers banked, would require thirty minutes or more, usually an hour.

RELATIVE LOCATION OF DIFFERENT PLANTS WITH RESPECT TO LOAD CURVE

Not only is it necessary to have the proper spare units for emergencies, but also to have the suitable generating equipment and have it located properly with respect to the load distribution. Certain features determine which of the types of units should be used. For example, during the day when the load is heavy the plants having the larger capacity, which are generally the hydro plants in this section, are used. When it is feasible, of course, the plants nearest the section demanding the greatest load are operated. When the load is light, the smaller units are used particularly when it is necessary to store water for the hydro plants. One of the most common faults of operation is the drawing of the ponds, during periods of peak demand, to such an extent that they will not refill during the off-load period.

Those charged with the operation of hydro-electric plants should make a thorough study of the pondage conditions existing at the various plants in the system. Charts should be prepared showing the kilowatt hours in each pond for various capacities for various average twenty-four-hour flows in the river. The possession of such data is especially important and useful at times of minimum flow when the operating department is using every means to have the

hydro-electric plants carry as much of the upper portion of the load curve as possible. Where pondage is sufficient, a weekly schedule of operating the pond may be worked out, such that the pond is at its lowest elevation Saturday noon but fills to crest elevation by Monday morning. Plants without pondage must be operated on the base of the load regardless of the flow in the river, except that plants having no ponds of their own may be able to operate of the pondage of another plant located upstream. Even though a material loss of head is obtained by drawing down the ponds, it almost invariably pays to do so, as the hydro-electric energy is thus placed where it is most valuable--in the peak of the load.

Most large power systems include steam plants as well as hydro-electric plants, and the economic operation of the hydro-electric plants is closely related to the operation of the steam plants. Generally speaking, the steam plants, at time of low water, are operated on the base of the load, and the hydro-electric plants having pondage are operated on the peak. This procedure tends to keep down the investment in steam generating capacity and also permits the generation of steam energy on a high load factor, which is much more economical than steam generation on a low load factor. In the case of systems having very long transmission lines, the contrary practice has been found more economical; that is, the hydro-electric plant is operated on the base, and the steam plants take the peak. This, however, is an

unusual method of operating and is due to the fact that the additional investment in the transmission lines required in order to bring the energy into the load center at a low load factor is so very heavy as to be uneconomical when all factors are considered.

The Sub-committee on Mechanical Reliability of Water Power Units of the National Electrical Light Association Hydraulic Power Committee reached the conclusion that hydro-electric plants are much more reliable than steam plants. From extensive and careful study, it has been found that power from a properly designed and constructed hydro-electric plant, delivered over a 100-mile 140,000-volt transmission line, is from two to six times as reliable at the delivery end of the line as is the power from a modern steam plant located at the delivery end of the line and delivering power there. This is a matter not usually appreciated in comparing the relative merits of hydro-electric and steam power. The inferiority of the reliability of a steam plant as compared with the hydro-electric plant and its transmission line is quite typical of the two methods of generating power. A steam plant with its multiplicity of machines operating at high speeds, high pressures, high temperatures, high metal stresses, and severe and repeated temperature changes, could hardly be expected to be as reliable as the extremely simple hydro-electric units operating at low speed.

The matter of hydro-electric reliability extends beyond the hydro-electric plants themselves, and renders the steam plants and also the transmission lines more reliable, inasmuch as an interruption to service in a steam plant can be made up for ten hours or more by the hydro pondage, and likewise an interruption to one transmission line can be made up for by drawing on the stored water and by the increased loading of another transmission line.

WEATHER KNOWLEDGE

Practically all central offices of a power system receive complete weather information over a teletype machine four times daily. Such information is very necessary for proper plant operation, especially for the hydro-electric plants. If certain weather conditions are known before hand, the stations may make necessary preparations to meet the conditions better. For example, when rain is expected, the hydro plants may supply more of the load than they ordinarily do without the danger of drawing down the reservoirs too much. Then when floods come, no power is wasted by having to allow the excess water to escape through the spillway. Complete weather knowledge is equally or more important when storms are expected. The daily reports show the direction and rate of speed of storm conditions which makes it possible to determine just when and where the system will be most affected. It may be necessary to have emergency crews on hand when storms come, or it may be advisable to break up interconnected systems and tie lines to prevent all lines from being affected when any one gets a fault. On the other hand, it is just as important to know when there is likely to be a drought so that hydro plants may operate accordingly.

Even though the central offices get the weather forecast regularly, there are certain rigid restrictions put

upon them as to its use. Government regulations do not permit the central office to give out weather forecasts for public use except those originated by the city offices of the U.S. Weather Bureau. Teletype forecasts from the airways offices of the U.S. Weather Bureau are furnished only for use in system operations as a public utility. Supplementary information from airline or other private meteorologists cannot be given out except to supervisory employees of power companies responsible for major property, and even then the sources of such supplementary information must never be given out.

TRANSMISSION AND INTERCHANGE OF FACILITIES

In an interconnected power system the transmission facilities of each branch are shared with other connected branches. The systems are all connected together to make one long continuous chain whereby power may be bought, sold or exchanged between various companies. Under certain conditions it is more economical to purchase power than it is to generate it at the point of distribution. This is particularly true when it would be necessary to carry spare generating units to supply the peak loads, because plants supplying the peak loads operate at a very low load factor which is uneconomical. On the other hand, it may be more economical to purchase power at fairly high load factors and operate plants of poor economy to supply the peak loads.

Such operating possibilities are extremely valuable in time of emergencies due to unnatural causes, or in time of normal clearances and switching, because of the ability to receive energy from another interconnected system and thus continue to supply the demand without interruption. Each day one of the connected companies agrees to regulate the voltage and frequency of the entire system. The governors on the units of the regulating plant are set so that they will be more sensitive than those on other units. An example will help to illustrate what happens under certain system conditions. Suppose there are three systems A, B,

and C interconnected and system B wishes to buy power from system A. First of all, the dispatchers of both system A and system B communicate with each other and make the arrangements. Then system B begins to decrease its generation and at the same time system A starts to increase. This process is carried on as far as desired at the rate of about 3,000 kilowatts per minute. However, if system A does not start to increase when B starts to decrease, energy will flow from C into B. Next let us see what would happen if all the generating units in system C were suddenly stopped while system A is regulating. When system C stops generating, system A is the first to respond because of the sensitivity of the governors on its units. However, if enough energy is drawn from the regulating system until it is no longer possible for it to maintain the voltage and frequency of the system, all the generating plants will automatically increase their output.

CONCLUSION

This paper has emphasized to a great extent the system operation and its importance. However, all of the procedure described and discussed is a part of the process of load dispatching and should be recognized as such. To most people load dispatching is a feature which is hardly heard of in system operation. To others it is a feature of system operation looked upon as wholly unnecessary. However, when one carefully scrutinizes the factors involved in system operation and is able to understand and appreciate its complexity, it is very improbable that such an observer would any longer question the necessity of a load dispatcher.

Even though the Chief Dispatcher and his assistants are necessary in carrying on the operating processes, there are others who have a part in carrying out the dispatching procedure. True enough the Chief Dispatcher has worked untiringly on the details and has probably reached the best conclusions, but he alone cannot possibly do the job. There are such persons as the Control Operators, Station Operators, Construction and Maintenance Crew and Line Crew who play a very important role in the operation procedure by working in coordination with the Dispatcher. All of the above mentioned operators and crews receive orders from the Dispatcher who keeps posted and informed regularly on all the conditions existing within the system.

From the foregoing it is obvious that efficient load dispatching is a difficult and responsible job which can be properly managed only by one who is thoroughly familiar with all the facilities of the system and who has had unlimited experience in dispatching. With a capable Dispatcher and a few assistants and co-workers a system is made to efficiently and economically serve its customers with a product that is indispensible.

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APPROVAL SHEET

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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