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Electric Traction on Pakistan Western Railway

By

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1. Introduction

1.1. The Pakistan Western Railway needs no introduction. As is well known, it is an undertaking owned and operated by the Government. It serves the West Wing of Pakistan, which has an area of 310 thousand square miles and a population of over 42 million.

1.2. The history of operation of the Pakistan Western Railway can be traced back to over a century, when in the year 1861, the line between Karachi and Kotri, a distance of 105 miles, was first brought into commission. Subsequently, 25 years later, on completion of other constructions, amalgamation and taking over of several company-managed railways operating in old Sind and Punjab areas by Government, emerged the well known North Western Railway, with a route mileage of 1,851. With the passage of time, more and more additions were made to the mileage. Before partition of India, the old North Western Railway formed the largest railway system in India, with a route mileage of 6,890.

1.3. With the partition of India in 1947, the portion of North Western Railway which was inherited by Pakistan, had a route mileage of 4,999. With the merging of 319 miles of the portion of Jodhpur Railway, which operated in Pakistan, the route mileage of North Western Railway increased to 5,318. The name of North Western Railway was changed to Pakistan Western Railway from the 1st of February, 1961. Pakistan Western Railway now enjoys the distinction of being the premier railway of Pakistan. As on 30th of June, 1965, it comprised 5,333.69 route miles, consisting of 4,635.77 route miles of Broad gauge (5′—6″) 318.20 route miles of meter gauge (3′—3 3/8″) and 379.72 route miles of narrow gauge (2′—6″). On the same date, its holding of rolling stock comprised of 701 Steam locomotives, 311 diesel locomotives, 38 diesel rail cars, 3,175 passenger coaches, and 33,644 goods wagons.

1.4. The Railway, on achievement of Independence, was inherited by Pakistan in a hopelessly rundown condition. Large-scale rehabilitation of

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track and equipment was urgently indicated. This, coupled with the fact that, the Railway was called upon to perform the stupendous task of transport of hundreds of thousands of refugees immediately after partition, posed an overwhelming challenge. The challenge was, however, met and the colossal task performed.

1.5. No sooner was the task completed than the Railway was faced with acute shortage of coal, due to suspension of supplies from India. Even this crisis was overcome, but at the cost of serious dislocation of traffic. The problem of fuel supplies for operation of its system provided the Railway food for serious thought. Can a railway system afford to depend entirely for its day to day operation on foreign supplies of fuel, which can be held back? For a railway, fuel supplies are the backbone of its existence, which when interrupted can completely ruin it and if subjected to undue price increase, can adversely affect its economics of operation. Independence from foreign supplies of fuel and saving in foreign exchange expenditure were the basic factors which prompted the Railway Administration to think of Electrification.

1.6. At the time of independence in 1947, the main motive power available for hauling trains with the Railway, was steam locomotives. There were a limited number of diesel electric locomotives in Karachi area for performing shunting duties in the port. For train operation most of the fuel had to be imported. Not only did this involve heavy drainage of foreign exchange, but fuel supplies were uncertain. With increase in the volume of traffic, from year to year, the foreign exchange payments were on the increase, and the supplies of imported coal continued to remain most uncertain as before.

1.7. Conversion of steam locomotives from coal burning to oil burning provided some relief. It was, however, apparent, that the solution lay elsewhere. The railway authorities had to start thinking seriously of adoption of other modes of locomotion, which would spare the railway the nightmares of the uncretain coal supply position.

1.8. There was yet another problem. Most of the boilers in the steam locomotives had been in service far in excess of their normal safe life. Safety of operation was resulting in their having to be worked at low efficiency. On this account, the consumption of fuel tended to increase considerably.

1.9. In the circumstances, the Railway decided to adopt diesel traction, and the first batch of diesel electric locomotives were placed in service in 1952. This action no doubt tided over, to some extent, the difficulty of coal supplies, and increased the transport capacity, but it did not provide any solution to the problem of increasing foreign exchange expenditure. Fuel oil for diesel traction had still to be imported. On the other hand, there was an additional

foreign exchange expenditure on spare parts, lubricating oils etc. However, that was about the best that could be done at the time. Electric traction was at the back of the minds of the authorities, but electric power resources and national grid network not having been sufficiently developed at the time, this line of action, for solution of the problem, could not obviously be pursued.

1.10. With the completion in recent years, of various Hydel Projects and establishment of thermal power stations utilising natural gas, there has been a rapid development of electric power resources. Electrical energy could be made available for traction. Time was therefore ripe to start thinking of examination of feasibility of introduction of electric traction on the Railway.

1.11. The Government of Pakistan lost no time over this. As the Railway Engineers had little experience of Electric Traction in general and of the new technique of AC Traction in particular, three independent foreign agencies were deputed to undertake technical and economic assessment of introduction of electric traction, on those sections of the Railway which would lend themselves to adoption of this form of traction. These foreign agencies were:—

(*i*) A team of experts from Japanese National Railways, which has an extensive network of electrified railway system. This team carried out a survey in the month of December, 1959.

(*ii*) A team of experts from a European Consortium. This team carried out a study during March and April, 1960.

(*iii*) A team of experts from United Kingdom Railway Advisory Service (UKRAS).

This team visited Pakistan during July, 1960.

1.12. Based on the recommendations contained in the reports submitted by the aforesaid team of experts, the P. W. Railway decided in January, 1963 to table a project for introduction of electric traction on two sections of the Railway. The Project was carefully examined by various authorities responsible for examination of such projects at various levels, such as Provincial and Central Development Working parties and the Planning Commission. Finally in May, 1964, the National Economic Council approved the project of Electrification of Khanewal-Lahore section, at an estimated cost of Rs. 1060 lakhs, including the foreign exchange component of Rs. 746 lakhs. Agreement was executed with the UK Government by the Government of Pakistan, for financing the external cost of the project soon after.

2. What is Electric Traction?

2.1. In simple words, the answer to this question is 'Electric Traction is a mode of traction, in which the motive power which hauls the trailing load is

propelled by electrical energy, which is not generated in the locomotive, unlike diesel electric locomotives, wherein diesel engine driven generators installed on the locomotive itself supply the electric power'. In the case of electric traction, a network of electrically charged contact wires or rails has to be installed for feeding electrical energy to locomotives.

2.2. The birth of electric traction can be traced back to nearly a century, when, in an Industrial Exhibition in Berlin, a miniature train driven by electricity was for the first time exhibited by one, Werner Von Siemens. Although this invention established that a vehicle could be moved and a load hauled by then so-called mysterious a force as electricity, without horses and clatter of hoofs or noise of steam, no one could apprehend at that distant date, what important and prominent a part electricity was destined to play in years to come, in the field of traction in general and railway operation in particular.

2.3. First application of the idea matured in the form of tramways and suburban railways, which took nearly thirty years. This was soon followed by its adoption on long distance railway trunk lines, for hauling passenger and freight trains. The development has since been rapid, which was only temporarily suspended during the two World Wars.

3. Why Electrify ?

3.1. In proceeding to examine the feasibility of introduction of electric traction on a railway system it is natural to compare its characteristics with those of the other established forms of traction *viz.* Steam and Diesel.

3.2. A steam locomotive is a self-contained unit and carries its own power plant. Its power output is, however, limited by the size of the boiler. For a locomotive of about 108 tons in weight (all available for adhesion), when starting and at speeds below say 20 m.p.h., the adhesion weight limits the tractive effort to about 53,000—58,000 lbs. Moreover, on account of the rotary motion being irregular, it begins to slip with a tractive effort about 20% below that of a diesel or an electric locomotive.

3.3. Like steam locomotive, diesel electric locomotive is also a self-contained unit, by virtue of which its optimum power output is limited. Its characteristics are very similar to those of steam. Due, however, to the regularity of its rotating motion as against reciprocating of steam, it possesses the advantage of better utilization of adhesion as compared to steam, *e.g.*, tractive effort at starting is 73,000 lbs. instead of 58,000 lbs. for the steam locomotive of comparable weight.

3.4. An electric locomotive unlike steam and diesel locomotive is not burdened with the need to carry its own power plant. Electric power can be fed

to electric locomotive from static power, stations through overhead contact line, in almost unlimited amounts, the only limitation being that the temperature of windings of traction motors must not exceed the permitted limits.[1]

3.5. By virtue of the technical features inherent in electric traction it provides certain basic reasons in favour of/and against electrification as under:—

A—*Reasons in favour of Electrification*

(*a*) *Railway reasons.*

(*i*) Electric locomotives have the most rapid rate of acceleration and can attain the highest speed, especially on rising gradients. Electrification, therefore, promises reduced running times for trains, consequently it is possible to run more trains, in other words an increase in the potential capacity of the section.

(*ii*) Electric locomotives have greater tractive effort, which means longer and heavier trains. A given quantity of traffic can, therefore, be conveyed with fewer trains. This results not only in better utilization of rolling, stock but also increases the section capacity.

(*iii*) Requiring no fuelling or watering, electric locomotives have a quicker turn-round, which results in their better utilisation.

(*iv*) Having far less moving or reciprocating parts, electric locomotives are easier and cheaper to maintain.

(*v*) An electric locomotive weighs less by about 50% per horsepower as compared to steam locomotive and by about 30% per horsepower as compared to diesel locomotive. A relatively smaller part of its output is, therefore, lost in driving itself. Greater power is available for transporting pay load.

(*vi*) With the introduction of electric traction, the wagons otherwise utilised for conveyance of fuel, become available for traffic which earn revenue.

(*vii*) Experience the world over is that, electrification results in enormous increase in traffic.

(*b*) *Economic reasons.*

(*i*) Adoption of electric traction affords considerable saving in foreign exchange expenditure on importation of fuel and lubricating oils.

(*ii*) Spare parts are not required to be stocked in such heavy proportions for electric locomotives, as are required for diesel locomotives. There is, therefore, not as much locking up of

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1. An electric locomotive is therefore capable of a much higher power output. It also possesses the advantage of better utilization of adhesion as compared to both steam or diesel locomotive.

capital, nor so much foreign exchange expenditure. There are far too many components of diesel locomotives which are subject to normal wear and tear, which can at best be only minimized but not eliminated.

(*iii*) In the event of war or some such emergency, the possibility of shortage of oils and spare parts which have to be imported, cannot be ruled out, when the Railway could very well find itself in trouble. Electric traction can be considered to render the advantage of being self-sufficient in this respect, as it will rely on a national product for its operation.

(*iv*) As the consumption of fuel oils in the world increases, which is naturally expected to, it will be necessary to search harder, drill deeper and go farther, to find additional oil reserves. As the reserves decrease, the need for synthetic oil will no doubt increase. The net result would be higher oil costs.

On the other hand the indications are that, with increased efficiency, the cost of electric power will rise at a slower rate. One should expect, therefore, that in years to come, as the difference between the cost of oil and electricity increases, the savings of electrification over diesel electric operation, would increase.

(*v*) Traction loads do not coincide with the normal peak loads of other users of electrical energy. This results in production of higher load factor at public utility generating stations. This type of load with its good diversity and high load factor is, therefore, very attractive as a base load for power companies and would result in favourable rates for electricity.

(*vi*) Railway electrification would form a part of the overall national plan, not only for the development of the Railway itself, but would also handsomely assist in the expansion of the power supply industry, and thus exercise a powerful influence on the industrial development of Pakistan as a whole.

(*c*) *Other reasons*

The last but by no means the least are the social and hygienic reasons which emerge out of electrification. These are:—

(*i*) Increased speed of trains and more frequent services provide additional facility to the travelling public.

(*ii*) Absence of smoke and noise helps to keep the atmosphere clean and healthier and train journeys more comfortable.

(*iii*) General cleanliness of this type of traction improves the working conditions for staff on locomotives, sheds and workshops.

B—*Reasons not in favour of Electric Traction*

(*i*) Whereas change-over from steam to diesel traction involves replacement of certain number of steam locomotives by a reduced number of diesel locomotives and provision of shed and workshop facilities; in the case of electric traction, additional capital outlay is necessitated, for installation of contact wire system, track feeder stations etc. etc.

(*ii*) In the case of A. C. high voltage system, yet additional item of capital expenditure in replacement of overhead tale-communication wires by underground cable, to safeguard against inductive interference on communication and signal system.

(*iii*) Since high voltage system demands increased electrical clearances, modifications are necessitated in bridges, tunnels etc. to provide them, which entails additional expenditure.

(*iv*) Being dependent on electric power supply from an outside source, the electric traction system can be compared to a centralised system, wherein failure at the centre or on the feeder lines of supply can paralyse the extremities. If the overhead line is damaged or if the power supply fails, electric traction comes to a standstill on the affected section and steam or diesel locomotive has to be called in for assistance. This appears to constitute a weakness of the system. Nevertheless, as a result of the developments relating to supply system, and technique of maintenance and operation, there is now a pool of experience to minimize the effect of more frequent minor interruptions to current supply, and in the event of damage at the contact line, feeders, sub-stations or power stations, current can be restored rapidly, in spite of the failure of a part of the equipment, by switching over to alternative channels.

(*v*) In the single phase A. C. traction system at industrial frequency there is a problem of load unbalance, as the traction sub-stations are fed by a three-phase high tension network from the public supply network. Experience has, however, shown that by adopting suitable permutation of the connection of different sub-stations to the phases of the grid, a good measure of load balancing is achieved, which has been found satisfactory in practice. Moreover, the magnitude of unbalance greatly depends on the proportion of the traction loads and the total load on the grid. In practice, the extent of unbalance in many cases has been found to be negligible.

4. Criterion for Electrification

4.1. There is no hard and fast rule and no single yardstick which can be applied to give a ready indication of viability of any electrification scheme. Different reasons justify embarkation on electrification schemes on different railways. For one railway it may be abundance of cheap electric power, while for the other it may be high volume of traffic or heavy gradients. Whatever may be the basic reason/or reasons for adoption of electric traction on any railway, it has to be financially or otherwise justified. On Pakistan Western Railway, the following factors were instrumental in arriving at the decision in favour of electrification.

4.1.1. *Fuel Supply*

In Pakistan, the railway system is and will continue to remain for generations, the life blood of the country's industrial and agricultural activities. Supply of fuel to fulfil its needs has therefore to be assured. Coal and oil deposits have so far not been found in any appreciable quantities. Hundred per cent reliance on imported fuel is not a desirable feature of railway operation. Prima facie case therefore exists, in favour of reliance by the Railway on electric power for future, which with the present stage of development both from the point of view of power from natural resources and transmission and distribution, can be safely considered to have fairly well advanced, to adequately meet the requirement, at least between Khanewal and Rawalpindi and beyond, up to Peshawar. It would no doubt not be a simple matter, to provide power from natural resources in the Karachi area, in the immediate future, but it would not be unreasonable to assume that in the long run cheap power supplies would be available in this area also, as in the rest of the country. It would be a matter of time for the North Western Grid to be inter-connected with a Southern Grid. Power supply to Karachi and Sibi-Quetta areas would also then be assured.

Railway's demand for electric power for traction would be permanent and stable. The developing power industry of a country has great need for a load of this type, for its success at various stages of development. Railway electrification is, therefore, expected to form part of a national plan, not only for the development of the railway but also for the expansion of the electric power industry and could exercise a powerful influence on the industrial development of the country as a whole.

From the point of view of fuel supply, therefore, the long-term objective of the railway should be its electrification, step by step, in line with the development of electric power supply, always keeping ahead of the general industrial and agricultural development of the country.

4.1.2. *Traffic Density*

With the general economic development of the country, it is reasonable to assume that the volume of traffic which the Railway would be called upon to carry will increase. This is amply substantiated by the following facts:—

1. During 1963-64, the figure for passenger miles showed an increase of over 60% as compared to the figure for 1950-51.
2. During 1963-64, the figure for ton miles of freight carried showed an increase of 116% as compared to the figure for 1950-51.

To carry this additional traffic the Railway had to run during 1963-64 over 188 additional passenger trains and 82 freight trains per day.

It is estimated that if the present rate of economic growth of the country is maintained, the Railway would be required to carry by 1969-70 increased passenger traffic to the extent of 18.3% and freight traffic to the extent of 39%, as compared to the traffic offering during 1963-64.

4.1.3. *System of Track*

By and large, the track system on P. W. Railway is single line and some of these sections are already saturated and carry trains to the limit of their capacity.

In planning for the future it has to be carefully examined whether, for dealing with the ever-increasing volume of traffic, electrification would meet the requirements or the track system would need expansion.

After careful consideration it has been decided that track expansion would not be necessary for the present, as electrification coupled with the modernization of signalling, will sufficiently increase the line capacities to meet the requirements for the present.

4.2. Large initial capital expenditure is necessary for introduction of electric traction. In examining the feasibility of electrification it is necessary to investigate on which section or sections, saving due to replacement of steam or diesel traction by electric traction will give sufficient return on the capital to be invested. Obviously choice must fall on such sections which have high density of traffic and particularly those which have single line or on such sections which have steep gradients.

4.3. On P. W. Railway, technical and financial implications of introduction of electric traction on the following sections were examined in detail:—

(*i*) Khanewal	..	Lahore.
(*ii*) Lahore	..	Rawalpindi.
(*iii*) Sibi	..	Quetta.
(*iv*) Karachi	...	Kotri.
(*v*) Karachi	...	Suburban.

5. Systems for Electrification

5.1. From the point of view of form of current, voltage and frequency, railway electrification falls under the following three main categories:—

(*i*) D. C. third rail, at about 600 volts.

(*ii*) D. C. overhead conductors, with voltage at 1500 Volts or 3000 Volts.

(*iii*) A. C. Single phase, overhead conductors, with voltage up to 15 K. V. at low frequency, generally 16⅔ or 25 cycles.

(*iv*) A. C. Single phase, overhead conductors, with voltage up to 25 K. V. with industrial frequency (50 Cycles).

5.2. Table No. 1 below gives the names of countries where these different systems are in use.

TABLE NO. 1

Countries and Systems of Electrification

D. C.		A. C. up to 15 K. V. Low Frequency		A. V. up to 25 K.V. Industrial Frequency
Australia ..	1500 V	Austria ..	15 K.V. 16⅔ cycles	Bulgaria.
Belgium ..	3000 V	Germany ..	15 K.V. 16⅔ cycles	China.
Brazil ..	3000 V	Norway ..	15 K.V. 16⅔ cycles	Congo.
Chile ..	3000 V	Sweden ..	16 K.V. 16⅔ cycles	France.
France ...	1500 V	Switzerland..	15 K.V. 16⅔ cycles	Great Britain
		U.S.A. ..	11 K.V. 25 cycles	Hungary
Great Britain	600 & 1500 V			India
India ..	1500 & 3000 V			Japan.
Italy ..	3000 V			Luxembourg
Japan ..	1500 V			Portugal
Netherlands	1500 V			Turkey.
Poland ..	3000 V			U.S.S.R.
Russia ..	3000 V			
Spain ..	1500 & 3000 V			
South Africa	3000 V			
U.S.A. ..	1500 & 3000 V			

5.3. The systems of electric traction mentioned in the preceding paragraph, as proved by experience gained over a good number of years by the railway administrations in various countries, permit of efficient train operation.

Each system has its merits and also limitations from the technical and economic point of view.

6. Historical notes on development of various systems of Electric Traction

6.1. Although it is not the intention to relate in this paper in any detail the development of the different systems of electric traction, for the sake of interest it would be desirable to mention some of the salient features, which are not only of historical interest but also of present-day importance.

6.2. Electric traction initially started with Direct Current, of voltages ranging from 100 to 500, its application being limited to operation of tram cars. This was followed by its adoption on railways, which called for an increase in the voltage. The limit of 500 volts was soon exceeded which reached 1500 volts. Three phase AC and single phase A.C. at low frequency were also used during this period.

6.3. The next phase of development witnessed the three systems *viz.*, 3 phase A.C., Single phase A.C. at low frequency and D.C. 1500 volts competing with one another. At that time all these three systems suffered with handicaps and efforts were directed to surmount their handicaps and difficulties.

6.4. A period of development followed next when advancement was achieved in the various co-existent system of traction. The 3 phase system succeeded in attaining four economical characteristics, which, however, could only give four economical speeds. The single phase gradually increased its specific power and the D.C. system attempted to use 3000 volts with rotary convertor sub-stations. Experiences were also successfully carried out during this period on the use of 3 phase current at standard frequency, with a view to simplifying the feed to the electrified systems. Perfection was also attained in the development of mercury as rectifiers and track feeder circuits breakers for high voltage D.C. which opened the field for electrification at 3000 volts.

6.5. During the early thirties, the choice of system for railway electrification lay between 1500 volts and 3000 volts D.C. and single phase A.C. (16.2/3 cycle), the 3 phase A.C. having been completely eliminated from the field.

6.6. The next phase witnessed the adoption of the three systems mentioned above in the various countries. However, there was also a new comer in the field, which was single phase A.C., at industrial frequency. This system was for the first time introduced in Hungary and experimented with in Belgium, France and Germany.

6.7. A test service with single phase A.C. on 50 cycles was started in Hungary in 1931 and subsequently adopted for use on the lines, Budapest-Hegyeshalom

and Budapest-Hatva . Germany started a test service on this system (50 cycles) in 1936, but for some special reasons decided in favour of maintaining 16.2/3 cycles system on its railway system and converted the experimental line to this low frequency.

6.8. France, after having achieved successful results with the experimental line in Savoy region in 1950, decided in favour of adopting the 50 cycles system.

6.9. In Belgium Congo, Bas-Congo-Kotanga section of Jadatville-Tenke line was electrified on 50 cycles, single phase and officially inaugurated in October 1952, which was followed by the sections towards Elizabeth Ville and Luena.

6.10. Turkey introduced electric traction with 50 cycles A.C. single phase for the first time in 1955 over the suburban section of European part of Istanbul.

6.11. The electrification programme in Japan consisted of electrification of about 2070 route miles, out of which approximately 1250 miles were to be electrified on single phase A.C., at industrial frequency. One section of Senzan line was electrified with 50 cycles in 1954, for test purposes and a 60 cycles system was brought into use on the HOKURIKU line in 1956.

6.12. In India electric traction started in the year 1925, with the opening of 16 Kms of electrified Section between Victoria Terminus (Bombay) and Kurla and Bandra, at 1500 volts D.C.

6.12.1. Between 1925 and 1936 further progress was made and more electrification carried out, covering a total route length of approximately 389 Kms. on the then G.I.P., BBC and S. I. Railway all on 1500 volts, D.C.

6.12.2. There was no further progress till 1958 when electrification of Howrah-Burdwan Section was completed, the system of traction being 3000 volts, D.C.

6.12.3. In view of the successful development of the A.C. system, on industrial frequency, at high voltages, India decided to adopt this system in preference to D.C., system and its second five-year plan (1956-1961) included electrification of 1081 route Kms., on the important lines of the Eastern and South Eastern Railways, carrying heavy mineral traffic. Further more, in their 3rd five year plan the Indian Railways have proposed electrification of a total of 1426 Kms. In addition, on 1171 route Kms., the existing D.C. system is proposed for conversion to A.C. system, at 25 KV. 50 cycles.

6.12.4. The position on Indian Railways by the end of 1964 was that electric traction on A.C., 25 K.V., 50 cycles was in operation over 1314 route Kms to which another 600 Kms. must have been added by now.

6.13. In Great Britain first application of electric traction for railway operation was in the year 1890 and up to 1914, railway electrification had been based

almost entirely on 660 volts D.C. supply, using conductor rail. Electrification at that time was however confined to suburban lines and London's underground railways. After the first World War, the third rail system was extended to cover the whole of London area and reached some of the coastal areas of Southern England, such as Portsmouth, Brighton, Eastbourne and Hastings.

6.13.1. The next phase of development in Great Britain was adoption of 1500 volts overhead system and in 1932, on the recommendations of a special committee, the highest voltage permissible for D.C. traction in the country was declared to be 1500.

6.13.2. Outbreak of the Second World War in 1935 suspended work on electrifications in Great Britain. After the war and shortly after nationalization of British Railways in 1948, a Committee was again appointed for reviewing the methods of electric operation at home and abroad and recommending the system or systems to be adopted in Great Britain for future electrification schemes. The necessity for appointment of this committee arose out of the emergence of diesel traction and a new system of A.C. electrification using supply of current at high voltage and of industrial frequency, in Hungary, France and Germany. This Committee, however, like the previous Committee recommended once again adoption of 1500 volts D.C. overhead system. Use of 3000 volts D.C. or single phase A.C. at industrial or lower frequency was not, however, ruled out by this Committee.

6.13.3. Meanwhile, important developments were taking place in the technique of A.C. electrification abroad and it was not till 1956 that the British Transport Commission decided to depart from the system hitherto followed in Britain and adopted as a standard 25 Kv 50 cycles A.C. system. The plan for modernization of British Railways presented in the same year included adoption of A.C. system of electrification on 1210 miles of trunk and suburban lines within the next 15 years.

6.14. Considerable progress has been achieved in the USSR towards railway electrification. By January, 1966, the total length of electrified lines had reached the figure of 25,000 route kms, out of which 8,000 kms at A.C. 50 cycle. The route length of main line railways in the USSR which is electrified is approximately 25% of the world mileage.

6.15. Other countries which have the industrial frequency high voltage A.C. system for electrification are China, Portugal, Turkey, Yugoslavia, Romania, Bulgaria, Argentine and Brazil.

6.16. The history of development of electric traction on railways in various countries of the world present an extremely interesting reading. Having started with a system using supply voltage of about 500 D.C. it soon reached

1500 and 3000 volts. Extensive application of the 1500 supply voltage in railway electrification is to be found in France, Japan and to a lesser extent in Great Britain, India, Australia, Netherlands, Spain and U.S.A. Low frequency A.C. system has been preferred by Austria, Germany, Norway, Sweden, Switzerland and U.S.A.

6.17. After having been received with some scepticism by the majority of railways in the beginning, the industrial frequency traction system can now very well claim to have outclassed the other well tried systems, which preceded it. This is evident from the fact that today all new major electrification schemes are being undertaken on this system. France, Great Britain, India, Japan, USSR, China are some of the countries which have decided to use the system in their future electrification schemes.

7. Choice of System for P. W. Railway

7.1. The question of the most suitable supply system for the electrification of railways, is by nature extremely complex. It is complex because it concerns not only the sphere of electric traction, but also that of generation of power and distribution to traction feeder sub-stations. Although technical and economic factors form the basis for selection of suitable system, but to these must be added commercial and political aspects. Objective comparison between the different supply systems, therefore, becomes extremely difficult.

7.2. At the present time the three main systems employed for main-line traction are:—

1. 1500 or 3000 volts D.C.
2. 15 KV, 16⅔ cycles, single phase A.C.
3. 20-25 KV, 50 cycles, single phase A.C.

7.3. For completely new electrification projects, where there is no need to allow for existing system, the 50 cycles, single phase A.C. system is likely to be selected, as it has proved itself to be undoubtedly the most economical system. The other two systems nevertheless retain their justification for adopting in the cases where renewals and extensions of existing traction systems are involved.

7.4. The direct current system makes use of D.C. series wound motors which, on account of their excellent characteristics of operation, meet the requirements of train working exceedingly well. This type of motor has proved its worth and has high operational reliability.

7.5. The system at 600 volts, 1500 volts or even 3000 volts D.C., however, involve high initial capital outlay on account of a large number of track feeder sub-stations and heavy contact rails or overhead wires.

7.6. The A.C. single phase system with high contact wire voltage permits of increased spacing between track feeder sub-stations and a comparatively lighter overhead contact wires, utilising lighter supporting structures. The initial capital outlay is, therefore, smaller. As expenditure on overhead contact system forms a large percentage of the total expenditure on electrification, this factor plays a predominant part in the economics of all electrification schemes.

7.7. The Government of Pakistan in deciding to have a thorough survey carried out by the three teams of experts had two alternatives before them, 3000 volts D.C. or high voltage, single phase A.C. at industrial frequency. For reasons of safety and economy it was considered unnecessary to consider either 600 V, 3rd rail or 1500 V overhead D.C. system. On considerations of economy the low frequency system was also not considered, as it involves provision of frequency converting equipment. The task undertaken was firstly to make a financial comparison of the two different forms of traction in terms of capital costs, annual recurring costs and savings, if any, in foreign exchange and secondly to make an assessment of the possible increase of traffic capacity and operating efficiency with the introduction of electric traction.

7.8. Comparison was made between the existing diesel electric traction and the aforesaid two systems *viz.*, 3000 V, D.C. and 25 KV, 50 cycles, single phase A.C. and in carrying out the comparison, a careful study was made of the most suitable design of electric locomotives, overhead equipment, feeder sub-stations etc. The figures relating to financial comparison are shown in Tables 2 to 6, which have been based on the anticipated volume of traffic by about 1970, the year by which electrification, if undertaken on any section, is expected to be completed.

7.9. Examination of the figures relating to financial comparisons reveals the following:—

7.9.1. The extra initial capital expenditure as compared to diesel electric traction is anticipated to be more in the case of 3 KV D.C. system than 25 KV, A.C. single phase, 50 c/s as shown against the various sections in Table No. 2.

7.9.2. The annual recurring expenditure is also estimated to be considerably higher in the case of 3 KV, D.C. system than for 25 KV, A.C., 50 cycles system. The details relating to annual recurring charges for two sections *viz.* Khanewal-Lahore and Lahore-Rawalpindi are shown in the Tables 3 & 4.

7.9.3. A study of Tables 3 & 4 would show that, if the annual recurring expenditure on electric traction is to remain equal to diesel electric traction:—

(*a*) For Khanewal-Lahore section, electricity charge for 3 KV D.C. system has to be as low as Rs. 0.045 per KWH, while 25 KV A.C.

TABLE NO. 2

Financial Comparison (Total Costs)

Section	Capital cost in lakhs of Rupees			Extra Capital costs (in lakh of Rs.) for		Extra cost of 3 KV, DC over 25 KV A.C. percentage.
	Diesel	25 KV AC.	3 KV D.C.	25 KV A.C.	3 KV, DC.	
Khanewal-Lahore ..	550.83	815.45	1015.09	264.62	464.26	75%
Lahore-Rawalpindi ..	582.31	843.47	1018.02	261.16	435.71	67%
Sibi-Quetta ...	671.65	865.94	938.42	194.29	266.77	37%
Karachi-Kotri ..	415.70	663.02	813.88	247.32	398.18	60%
Karachi-Suburban ..	159.32	247.96	299.10	97.64	139.78	43%

TABLE NO. 3

Financial Comparison (Annual Recurring Costs)

Section			Annual Recurring Expenditure		
			Diesel Electric	25 KV A.C.	3 KV D.C.
Khanewal-Lahore	Depreciation	..Rs. Lakh	19.15	13.02	18.06
	3½% interest	.. ,,	19.28	28.54	35.53
	Fuel or Power				
	Maintenance	.. ,,	35.97	41.29	28.21
	Locomotive	.. ,,	23.17	11.16	10.33
	Overhead	.. ,,	..	2.93	2.93
	Track side stations	.. ,,	..	0.63	1.97
	Total	..Rs. Lakh	97.57	97.57	97.57
	Electricity Cost Rs./KWH		..	0.075	0.045
Variation of Interest rates on extra capital with different costs of Electricity, if annual diesel and electric charges are to remain equal.	0.03 per K.W.H.	..	..	12.87%	5.53%
	0.04 do	..	..	10.78%	4.18%
	0.05 do	..	..	8.69%	2.84%
	0.06 do	..	..	6.60%	1.50%
	0.07 do	..	..	4.51%	0.16%

TABLE NO. 4

Financial Comparison (Annual Running Costs).

Section			Annual Running Expenditure		
			Diesel Electric	25 KV A.C.	3KV D.C.
Lahore-Rawalpindi	Depreciation	..Rs. lakhs	20.24	13.35	18.98
	3½% Interest	.. do	20.38	29.52	35.63
	Fuel or Power				
	Maintenance	.. do	36.71	43.07	30 65
	Locomotives	.. do	22.64	10.86	10.05
	Overhead	.. do	..	2.40	2.40
	Track side stations	.. do	..	0.67	2.16
	Total	.. do	99.97	99.97	99.97
	Electric cost Rs/KWH	..	..	0.078	0.050
	Rs.				
Variation of interest rates on extra capital with different cost of electricity, if annual diesel and electric charges are to remain equal.	0.03 per K.W.H.	..		13.61%	6.28%
	0.04 do	..		11.49%	4.55%
	0.05 do	..		9.36%	2.83%
	0.06 do	..		7.24%	1.10%
	0.07 do	..		5.11%	..

could bear the electricity cost up to Rs. 0.075 per unit. Likewise, at the electricity supply cost of Rs. 0.06/KWH 25 KV A.C. system could bear an interest rate up to 6.6% while 3 KV D.C. system could bear the interest rate only up to 1.5%.

(*b*) For Lahore-Rawalpindi section, electricity charge is not to exceed Rs. 0.05/KWH, in the case of 3 KV D.C. while 25 KV A.C. system could bear electricity cost of Rs. 0.078 per unit. Likewise, at the electricity supply cost of Rs. 0.06/KWH, 25 KV A.C. system could bear an interest rate up to 7.24% while 3-KV D.C. system could bear the interest rate only up to 1.10%.

7.9.4. Figures relating to annual recurring expenditure for other sections of the railway similarly show results in favour of the A.C. system. For the sake of brevity tables containing figures for sections other than Khanewal-Lahore and Lahore-Rawalpindi have not been included in this paper.

7.9.5. Comparative figures of estimated foreign exchange expenditure, initial and recurring, are shown in Tables 5 and 6 below. It would be seen from Table No. 5, that 3 KV, D.C. system is estimated to cost more as compared with 25 KV AC. as under:—

(*a*) For Khanewal-Lahore Section by 72%

(*b*) For Lahore-Rawalpindi Section by 60%

(*c*) For Sibi-Quetta Section by 19%

(*d*) For Karachi-Kotri Section by 48%

(*e*) For Karachi Suburban Section by 44%

TABLE NO. 5

Financial Comparison (Foreign Exchange Costs)

Section	Capital cost in lakhs of Rupees			Extra foreign exchange costs (in lakhs of Rs) for		Extra costs of 3 KV DC over 25 KV AC%s.
	Diesel Electric	25 KV A.C.	3 KV D.C.	25 KV A.C.	3 KV D.C.	
Khanewal-Lahore ..	435.23	574.35	660.06	119.12	204.83	72%
Lahore-Rawalpindi ..	481.25	607.35	681.89	126.10	200.64	60%
Sibi-Quetta ..	555.08	664.75	685.85	109.67	130.73	19%
Karachi-Kotri ..	343.55	472.97	534.10	129.42	190.55	48%
Karachi-Suburban ..	131.67	175.64	196.24	43.97	64.57	44%

7.9.6. Saving in annual recurring foreign exchange expenditure is expected to be more on all the sections surveyed, in the case of 25 KV, single phase, 50 cycles system, than 3 KV D.C. system (see Table No. 6).

7.10. The choice was therefore obvious. For railway electrification, 25 KV A.C. single phase, at industrial frequency, was considered to be best system for adoption on P. W. Railway, taking all factors into consideration.

TABLE NO. 6

Foreign Exchange Costs (Annual Recurring Costs in Lakhs of Rupees)

Section	Annual Recurring costs			Saving with electric		Annual saving as percentage extra capital cost		Number of years of saving to equal extra capital cost	
	Diesel Electric	25 KV A.C.	3 KV D.C.	25 KV A.C.	3 KV D.C.	25 KV A.C.	3 KV D.C.	25 KV A.C.	3 KV D.C.
Khanewal-Lahore	47.38	23.86	26.80	23.52	20.58	19.7	10.0	5.1	10.0
Lahore-Rawalpindi	48.89	24.93	27.51	23.69	21.38	19.0	10.7	5.3	9.4
Sibi-Quetta	43.31	26.67	27.24	16.64	10.07	15.2	12.3	6.6	8 1
Karachi-Kotri	41.23	19.36	31.87	21.37	19.36	16.5	10.2	6.1	9.8
Karachi-Suburban	13.41	7.83	9.46	5.58	4.95	12.7	7.7	7.9	13.0

8. Choice of Section for electrification

8.1. Having selected the system for adoption, the next exercise was the selection of the most suitable section for introduction of electric traction. Khanewal-Lahore section was selected for the purpose, as the terrain of the section being generally flat and there being no major bridges to be encountered, its electrification was not likely to involve any major engineering work. This section forms part of the main passenger trunk line of the country. Power supply is available and taking of High Voltage supply from West Pakistan WAPDA is not likely to involve any difficulty.

8.2. Lahore-Rawalpindi section is estimated to give as good financial results as Lahore-Khanewal section. Power supply is conveniently available for this section also. Electrification of the section will, however, involve the difficult engineering work of provision of electrical clearance through the tunnels between Lalamusa and Rawalpindi, as also raising of a number of over-bridges throughout the section.

8.3. In view of the more difficult engineering works involved over Lahore-Rawalpindi section, Khanewal-Lahore section has been given priority over it. Lahore-Rawalpindi section has been programmed for electrification after completion of Khanewal-Lahore section.

8.4. Sibi-Quetta section having severe gradients is undoubtedly most suitable for electrification. This section offers the biggest total return both at the present and anticipated future levels of traffic. Electricity supply for traction purpose is, however, not readily available in this area. Its electrification cannot, therefore, be considered at the moment.

8.5. Karachi-suburban and Karachi-Kotri sections do not carry sufficient traffic at present to justify electrification. Moreover, electricity supply is not available for traction, in these sections. These areas are served by the major port of Karachi and have large concentration of labour. It is anticipated that the traffic levels on these sections are bound to increase beyond the general level of increase in other sections of the Railway. Subject to availability of electric power, electrification of these sections may be profitable proposition in due course of time.

9. Concluding Remarks

9.1. The financial comparisons discussed at length in the preceding paragraphs enabled the Railway to select the system of electric traction for adoption and the section most suitable for electrification. Detailed financial implications were examined next, after the rate at which WAPDA was prepared to supply electrical energy was made known and the loan terms for external expenditure were finalised. The latest position in this regard is that, WAPDA has agreed to charge the Railway for electricity for traction a rate of 7 paisa per unit, up to 31st December, 1970 and thereafter at the rate of 6.5 paisa per unit. The Government of United Kingdom has offered to finance the foreign exchange element of the cost of the project under a special Railway Electrification Credit Agreement. The loan offered is to be interest-free.

9.2. The financial implications of electrifying Khanewal-Lahore section, the section selected for electrification have been re-examined in detail recently by the Railway after getting a Comprehensive Project Report prepared by a team of experts from U. K. which incorporates the uptodate capital cost figures of locomotives, telecommunication cable, sub-station, overhead equipment etc. It is estimated that in the matter of overall annual recurring expenditure, there would be a saving of about Rs. 14.5 lakhs. It is, however, in the annual foreign exchange expenditure that the saving is most marked. The annual saving is anticipated to the tune of Rs. 4.00 million. The extra foreign exchange

expenditure on electrification is estimated to be paid back in less than ten years time by the saving.

9.3. The Pakistan Western Railway in deciding to introduce electric traction on Khanewal-Lahore section has taken a big step in the right direction, but if it is to derive real benefit from this decision, electrification shall, no doubt, have to be extended to other sections as well.

9.4. Gone are the days when the railway in Pakistan enjoyed a monopoly in the field of transport of goods and passengers. Road transport and the Air Line have already started offering a competition. If Pakistan Western Railway is to continue to maintain its supremacy and play its due part as premier carrier of traffic it cannot but make full use of all the modern methods and technique. In almost all the developed and industrialised countries of the world today, electric traction has been recognised as one of the most important means of speeding up traffic. P. W. Railway would do well to take full advantage of this new technique available.

9.5. The overwhelming benefits accruing from electric traction are such that, even countries like France, Great Britain and India, who claim a measure of self-sufficiency in fuel, are going all out for electrification of their trunk lines. Pakistan has no indigenous fuel worth mentioning. On the other hand, its electric power resources are fast developing. Supply of electric power for traction is likely to be made available in full quantities.

9.6. The decision to electrify the railway is, therefore, the correct one. The railways in Pakistan, as the railways in other countries, play a vital role in their overall development. To enable them to do so, they must continue to modernise and amongst the accepted means of achieving this objective, electric traction ranks the foremost.