MagnetoHydroDynamics (MHD): Making a case for Innovative Generation Pakistan Environment

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***Abstract*:** Energy Crisis is one of the major issues of Pakistan. There are many reasons of deficit in demand and supply energy such as fuel cost, inefficient power plants and non-utilization of indigenous resources. Most of the public sector thermal power plants (GENCOs) currently operating in the country are not more than 30% efficient, which reduces the output power drastically and result in high tariff rates. In this scenario, the installation of efficient power plants has a high potential to overcome the energy crisis significantly. Magneto Hydro Dynamic (MHD) has the capability to increase the efficiency of existing power plants and utilization of vast coal reserves with negligible effects of environmental pollution. Generators In this paper the review of MHD generating technology is presented and the current research including a number of innovative MHD cycles are discussed. The prospects of this technology are explored in generation sector of Pakistan as a solution to energy crisis and especially for the utilization of vast coal reserves of Thar. Issues and challenges are considered for implementation of this technology and finally the roadmap for its implementation in our environment is discussed.

***Keywords*: MHD Generator, energy crisis, environmental emissions, generation efficiency, Thar coal.**

I. INTRODUCTION:

Pakistan with population over 190 million is in darkness due to energy crisis. The current generation mix in electricity sector is primarily based on thermal and hydel sources. State of industry report NEPRA 2015 [1] states the generation capacity of Pakistan as 24,823 MW. In this generation capacity thermal has the highest share of 67.74%, which is primarily based on oil and gas while the coal has a share of 0.15% only. The thermal generation in government sector is done by power plants named as GENCO 1-4. The thermal efficiency of these plants is not satisfactory and three out of the four GENCOs have efficiency lower than 30%. The GENCO-IV has the lowest efficiency of the four plants and it stands at 17.74% only [1]. Similar results are obtained in [2] that show that public owned power plants perform poorly compared to private owned power plants. The imported oil as a fuel and low efficiency of power plants results in higher tariff to the consumers. High tariff acts as a negative element in economic growth of country. The industrial tariff comparison in south Asian countries shows that Pakistan stands second highest in industrial tariff [3] as in shown in figure 1

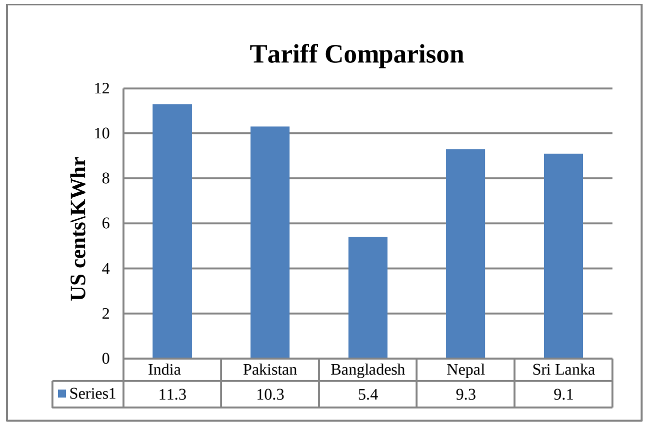

Fig 1: Industrial Tariff Comparison

The current deficit in generation and demand stands at 5625 MW [1] and forecast by expert group on energy of China-Pakistan economic corridor (CPEC) suggests that this shortfall will further rise to 10844 MW by the year 2020.

Currently environmental pollution is one of the main concerns in the world and this has led to renewed interest in generation technologies that are less pollutant. The current parameters of Pakistan in environmental performance are not good. Pakistan stands at 148 out of 178 countries ranked on Environmental Performance Index 2014 [4].

In this scenario of less efficient power plants, major dependence on imported fuel and negligible contribution of indigenous resources suggests for technology that is highly efficient, less environmentally pollutant and utilizes the indigenous resources. One such technology is MHD power technology that has the potential to exploit the vast coal reserves of Pakistan in an efficient manner with less environmental burden. Pakistan has vast reserves of coal more than 185.5 billion tones [5]. Until now only 150 MW power plant has been established on indigenous coal. Using the conventional technology based on Rankine cycle for power generation with coal has the associated problem of environmental pollution and further thermal efficiency of these plants is low limited by the second law of thermodynamics [6]. The coal reserves can be tapped with MHD technology that has high efficiency up to 60% [6-11] that can be scaled up to 80% or more through technology development/research [12] further

MHD technology has quite less environmental burden. The efficiency comparison between different power generation systems clearly indicates the supremacy of MHD generation over the other systems as shown in figure 2 [13]

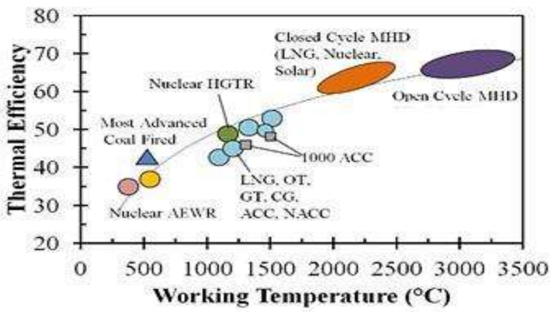

Fig. 2: Efficiency of Power Generation Systems

II. MHD TECHNOLOGY

MHD is a plasma technology that can be an alternative to steam turbine power plants of Thomas Edison's era [9]. In conventional generators solid conductors are used for production of voltage while in MHD generators electrically conducting fluid is used as conductor that passes through MHD duct surrounded by strong magnetic field, as a result of this movement voltage is induced at the electrodes placed along the MHD duct. Voltage produced is DC in nature. The voltage induced is a function of the fluid velocity (m/sec), magnetic field strength (Wb/m^2) and inter-electrode gap width (m) [14]. The basic schematic of MHD generator is shown in figure 3 [15]

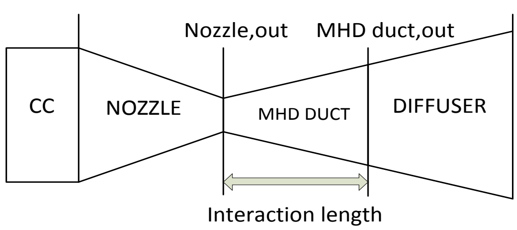

Fig. 3: Schematic of MHD generator

Due to static configuration MHD can work in the higher temperature regime than conventional systems. The temperature is typically 4500 ^{0}F and the magnetic field used is 5-7 tesla [9]. The magnetic field can be produced by two configurations either iron core water cooled magnet or superconducting magnet. Superconducting magnets are superior due to their operation with almost no power loss. The fossil fuel MHD is compatible with all types of fuels [7, 11]. The USA research emphasized on the coal fired MHD while in Russia gas fired MHD systems were operated for a long time. Similarly in JAPAN research continued on oil fired based MHD systems. Currently the major concern in MHD technology is coal fired systems whose capability of high efficiency and less CO2 emissions are higher than any other coal fired power plant [16]. MHD generator due to static configuration is more reliable [9] and has flexibility for all modes of power plant i.e. base load, peak load and emergency service [6, 7]. Cost comparison of MHD generators with conventional generators suggest that initial cost of MHD generators comparable with conventional power plants and operation and maintenance cost is lower than conventional power plants [6, 7].
There are many environmental benefits of MHD power generation technology [9-11, 16-19]. MHD can utilize the sulphur laden coal and sulphur emissions are eliminated due to conversion of sulphur oxides into potassium sulphate by chemical reaction with the seeding material. And with some changes in the design of boiler and combustion controls the desired levels of nitrogen dioxide emissions can be achieved. MHD is the only coal conversion technology that minimizes CO2 emissions and facilitates the removal of acid rain constituents economically.

III. MHD CYCLES

There are basically two types of MHD cycles open cycle and closed cycle. Each having its own advantages [19]. In open cycle the gaseous combustion products of fossil fuel are used as the working fluid and after passing through the generator they are sent to the atmosphere or to the bottoming steam generator shown in figure 4 [20]

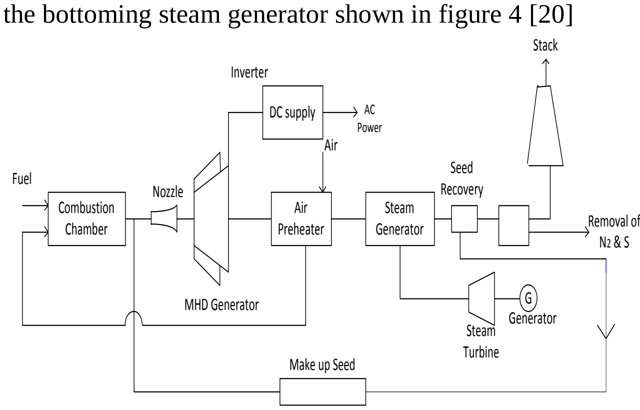

Fig. 4: Open Cycle MHD Generator

While in closed cycle some inert gas, liquid metal or vapor mixture is used as the working fluid and energy from combustion products is supplied to the working fluid through a heat exchanger. After passing through the generator the fluid is returned to the heat source. The schematic is shown in figure 5 [20]

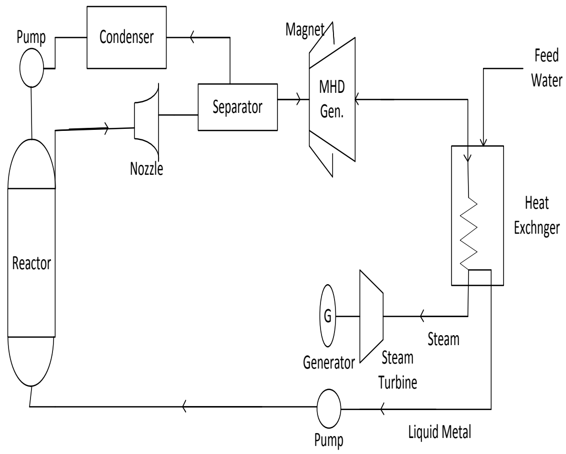

Fig. 5: Closed Cycle MHD Generator

The use of open cycle or closed cycle is still an open question and needs further research. The US Energy Conversion Alternatives Study (ECAS) study[21] supports the open cycle system. The operating temperature of open cycle system is higher while closed cycle systems can operate at lower temperature [6, 18, 19]. The operation and maintenance cost of closed cycle systems is lower [18] and their size is compact hence the size of the superconducting magnet required reduces but closed cycle system would require a costly heat exchanger hence pushing up the cost of electricity. On an economic scale the closed cycle systems are suitable for small power plants up to 100MWe while the open cycle systems become economical above 200 MWe [6].

IV. OPERATION EXPERIENCE AND RESEARCH

Although the research has been going on in the MHD technology development since 1940s but the recent interest has revived the topic [22]. MHD development and implementation programs were carried out in different countries each having its own characteristic. The research and development was carried in USA, USSR, China, India, Poland, Japan and Rumania. The development as pursued in different current is reviewed in [23] over the time period 1959-1993. In USA research carried out at two research facilities named as Component Development and Integration Facility and Coal Fired Flow Facility had the objective of establishing the necessary engineering database for the commercialization of the technology. In Proof of Concept Program (POC) technical, environmental and design data were gathered through long duration tests of MHD prototype plants. This program was terminated due to budget constraints but engineering database is sufficient to allow the design of large MHD commercial power plant. In Russia the research was focused on U-25 MHD power plant facility with the long term objectives of investigation and component development. In china retrofitted power plants were selected as technical approach for the implementation of the technology [17]. While in India, japan, Poland and Rumania test facilities were established ranging in size from 4-5 MW and theoretical research and experimental test runs were done at these facilities. As a result of all these efforts much of the operating experience exists for MHD generators for example U-25 facility that was a natural gas fired MHD system provided power and heat for the residents of Moscow for several years until early 1990s[22, 24]. Sufficient technical grounds exist for design and manufacture of all the nonstandard MHD components. One of the most important component is superconducting magnet and for this in past researches were carried out such as Japanese National research and Development Program for superconducting magnets that produced magnetic field of 75KG with the pancake shaped superconducting magnet. Similarly superconducting MHD magnet Technology Development Program was pursued in USA aimed at technology development, technology transfer and subsequent development by the industry for MHD program. Also in 1982, 6 tesla superconducting magnet was made in Argonne National Laboratory. Similarly successful test runs were conducted for the topping components of MHD-steam combined cycle system, inverter system and environmental emission were verified [6]. No any fundamental technical problem exists in the process of commercialization of MHD technology and there exists a need to only improve upon the already tested components [7].

V. INNOVATIVE MHD CYCLES AND DESIGNS

Besides the conventional fossil fuel MHD system, a number of innovative methods have been suggested. MHD systems can be designed that are nuclear heated [10, 25]. With appropriate high temperature reactors in the range of 2000-2500K these nuclear-MHD systems have efficiency realizable up to 60%. In [26] optimization has been done on MHD generators with respect to magnetic field utilizing lead as the working fluid. This analysis shows that when MHD generators are applied as generators any desired power density can be obtained by controlling only the magnetic field. Results of systems analyzed in [26] gave a power density of approximately 0.5 MW/m3 and has the potential of additional capacity if combined with BREST reactor design.

Similarly triple cycle was proposed powered by solar energy with MHD topping, intermediate Brayton and bottoming Rankine cycle. Very high efficiency in the range of 70 % can be achieved with concentration ratio of 10000 suns [27]. The schematic of solar triple cycle is shown in figure 6 [27]

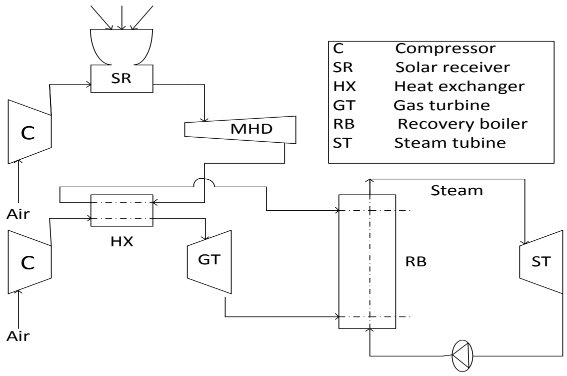

Fig. 6: Solar triple cycle

The development of solar MHD is being carried out by different companies/universities such as partnership of Rensselaer Polytechnic Institute and Concentrating Solar Power Utility. This solar based cycle can play an important role in Pakistan due to high potential of solar energy of annual mean 5 KWH/m^2/day [28] but for this high precision concentrator and high temperature materials are developed.

Similarly to reduce CO2 emissions, CO2 recovery type plant was proposed by Prof. N. Kayakawa [13]. In this plant coal synthesized gas is burned in an atmosphere of oxygen and with heat recovery systems of regenerative coal gasification process, fuel preheating and steam decomposition as shown in figure 7 [13]

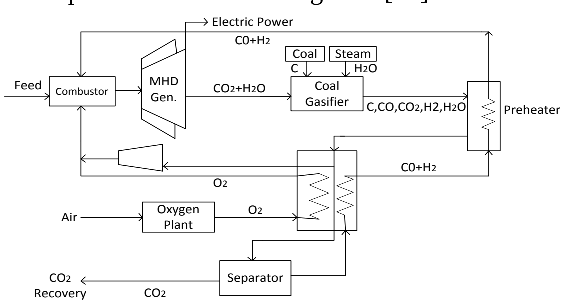

Fig. 7: CO_2 Recovery Type MHD Generator Plant

Other cycles also exist such as Energy Recirculating LNG/MHD system proposed by Prof. Y Okunu [13].

Many new designs have been given recently related to MHD generators and they offset many disadvantages attached with conventional designs. In [29] a new configuration of Disk MHD generator has been given that segments the generator into many parts and it has been shown numerically that such configuration results in more stable plasma ionization and performance improvement in terms of efficiency and power output than conventional generator. The optimum values were obtained with angle 50-10 degrees and 36-72 parts. Another design of MHD generator that can be useful for industrial applications is given in [30]. This Inductive MHD generator overcomes all the common drawbacks such as need for strong magnetic field, seeding material requirement for higher conductivity and tough requirements for electrodes that are necessary part of the conventional MHD generator design. Finally a Simulink model is developed for the inductive generator and results obtained from simulation showed good agreement with expected results of the generator.

VI. INTEGRATION STUDIES

The current power system is an AC system while NHD generator produces high DC voltages hence the interconnection of this technology into existing power system will pose special problems. These studies both in dynamic variations and transient studies [31, 32] suggest positive impacts of this integration. MHD generator provides damping and results in increased network stability. Due to low energy storage capability of MHD generator the fault currents and surges are reduced. MHD response to fuel supply is instantaneous. Hence this integration does not degrade the performance of existing system except for higher inertia requirement for the associated alternator.

VIII. RETROFITTED MHD POWER PLANTS

MHD power generation becomes economical for a plant size of 200 MWe. In U.S.S.R the attempt was to directly jump from test facility operating experience to commercial plants of the capacity of 500 MWe, but as research is still needed for the refinement of the MHD components. Due to these grey areas other countries adopted an alternative method of tis implementation via retrofitted MHD power plants [33]. China adopted this strategy of retrofitted MHD plants as technical approach for implementation of this technology in their existing power plants [17]. In retrofit approach the MHD generator is added as topping cycle to existing thermal cycle of power plant and its exhaust gas due to high temperature is utilized in the bottoming cycle for steam generation. This approach of retrofitted MHD power plants will reduce the investments required for the demonstration of technology and an added advantage of the conversion of existing power plants to coal fuel [18].

Assessment studies of retrofitted power plants were performed by Southern California Edison Company and guidelines were formulated both during construction and later in operation [18]. The primary purpose of retrofitted power plants is to provide the needed operation and maintenance experience with this new technology and in helping to understand the inherent risks of this new technology. The MHD plant should not compromise the reliability of existing plant and not affect the operation during site construction and in case of major fault in its own components. From this MHD plant should provide the return on investment. MHD is an evolving technology so the plant should be able to accommodate the technology changes that occur after its installation.

VIII. CURRENT RESEARCH

There is much of the research going on in the field of MHD technology. Specifically researchers were brought together to discuss the latest trends and directions in the field of MHD power technology research at MHD power generation workshop [34] and a number of important observations and latest research were discussed. Significant progress has been made in the field of materials, cryogenic refrigeration and power electronics and all these developments will have an impact of future MHD systems. The superconducting magnet development as has resulted from the efforts of CERN fusion is applicable to MHD technology. In order to better understand the MHD operation there is a need of better and reliable models and simulation tools that are based on experimental validation data. The current trend is towards the renewable energy, in this scenario MHD technology is a good option together with renewable or biomass based plants.

Many powerful simulation codes are available for MHD generators and through numerical analysis many innovative designs of MHD generators and performance analysis of cycles utilizing MHD generators has been demonstrated [15, 35-37]. In [35] 3D numerical simulations have been carried out for Faraday type MHD generator and the effects of load factor and magnetic field on the power generation performance have been investigated. In [15] different power plant configurations employing MHD generators as topping cycle have been investigated and it is shown that by using syngas high system efficiencies up to 60% are possible due to better heat recovery. The possibility of coupling MHD generators to two power stations in South Africa namely Ankerlig and Gourikwa have been analyzed through simulations [36] and it has been shown through theoretical models that overall generating efficiency of these plants will increase. MHD research has a setback and the main reason of abandoning the project of MHD was economic but the economics of that time did not include the cost of CO2 capture [37]. It is a known fact that oxy combustion can help in CO2 capture because the combustion products mainly consist of CO2 and H2O. In [37] model results are derived from parametric study highlighting the main differences between previous approaches and modern oxy combustion systems. It is argued that if MHD generator is used as topping cycle with oxy combustion, due to higher temperatures in oxy combustion the electrical conductivity will be higher and hence higher power densities are possible in MHD generators. This will offset oxygen separation penalties by deriving more power from the system and finally in this paper gas electrical model is developed using updated MTCS (momentum transfer cross section) data.

IX. MHD TECHNOLOGY IMPLEMENTATION STEPS IN PAKISTAN

Adoption of new technology is important. How a nation adopts a new technology affects everything from cost of production to per capita income [38]. Same applies in the case of MHD technology adoption. Its adoption will allow Pakistan to utilize its vast coal reserves efficiently that would affect overall scenario of energy crisis, tariff, industrial cost of production and overall economic growth. The primary attraction of adoption of MHD technology is in the utilization of coal reserves. The primary reserve being the Thar where 175.5 billion tons of coal exist. As outlined earlier there is no technical barrier in the implementation of the technology, most of the research has been carried out around the world and sufficient engineering database exists both for the design of standalone systems and retrofitted MHD power plant. Based on the experiences of the other countries as in [17, 23, 33, 39] the following steps are needed for the implementation of technology.

1) Establish the suitability of Pakistani coal for MHD power generation.
2) Design and development of pilot plant in the range of 5 MW.
3) Design and development of retrofitted power plants.
4) Ehen the technology is firmly established then only the large scale MHD generators standalone applications be considered.

First of all the suitability of the coal be established for the MHD generation technology as for example done in [40] for Indian coal. The effects of constituents of coal on the performance of operation must be established and the analytical evaluation must be done at different temperatures and pressures. The analysis of Thar coal as in [41] categorizes it as Lignite coal but it has the advantage of low to moderate sulphur compared to world average of 2.42%. Lignite coal is suitable for gasification because of its high reactivity. Initially as the fuel the directly coal fired MHD facility would be complicated to operate due to slag or ash formed by mineral matter and sulphur based compounds. Further the slag composition and properties vary within a seam and from seam to seam thus complicating the performance[42] hence initially the coal gasification must be used to supply the fuel that is free of mineral matter and sulphur. This approach of MHD generator working on the gasification products of lignite is established [43]. Later on when competence is developed with this fuel then through research shift can be made to directly coal fired MHD power plants.

After the suitability is established then the performance must be studied with the laboratory scale MHD generator. Design and development of pilot plant facility of the size of 5MW with the primary objective of scientific and technology investigations and developing the necessary competence in the operation of the facility. The most important step is the development of MHD components and establishes market for these components. The design capabilities with the period of time will be scaled up to large size power plants. Most important areas of research for the development of technology include the superconducting magnets and the high temperature materials. Currently some of the research is going on in superconductivity in the country but that is not enough to produce the high magnetic field strength magnets for the MHD power plant hence the first designs must use the iron core and water cooled magnet for the MHD power plant. The pilot plant should have the capability to incorporate design changes and the latest research that is carried out here and around the world. The acceptability of the MHD technology directly depends on the market availability and cost of major components which in itself is dependent on the learning curve of the manufacturers [18]. With these accomplishments made the shift to retrofitted power plants will be easy and that involves the necessary competence in the operation of inverter systems as the voltage produced is DC in nature. Successful operation of inverter systems were carried out by EPRI. Currently no any experience exists in the country with the high voltage DC systems but with CASA 1000 project the HVDC grids will be part of the Pakistan grid.

X. CONCLUSION

The MHD technology has huge potential for Pakistan generation environment both in utilization of coal resources and solar energy. Further as the renewable market is developed the MHD will find application in that technology as well. Much of the research has already been done which shows promising results in simulations and there is a need to develop initially the prototypes and then on large scale MHD generators, then there will be a need to establish the local market for MHD components.

XI. FUTURE WORK:

Two things can be done at laboratory scale/university level first to establish the suitability of Pakistani coal for MHD power generation and secondly the design, development and testing of MHD generator in the range of watts.

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