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Economic Dispatch for HVDC Bipolar System with HVAC and Optimal Power Flow Comparisons using Improved Genetic Algorithm (IGA)

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***Abstract*-With the growing need for reliable, clean and economical electrical energy as a result of urbanization and technological advances, power system networks have to be continuously upgraded to meet the increasing demand. However, the existing matured AC power systems are limited by strict standards for reliability, stability and right-of-way (ROW) permit for new transmission lines. As such, high voltage direct current (HVDC) systems provide viable techno-economic solutions to these problems and hence play a very crucial role in modern power systems. In this paper, an Improved Genetic Algorithm (IGA) has been successfully implemented on MATLAB environment and tested on an IEEE 9-Bus system to simulate the HVDC-Economic Dispatch (ED) [HVDC-ED] problem. As compared to the conventional GA and other pure methods, IGA has been found effective in solving HVDC-ED problem since it works with a small population, involves progressive improvement and converges to a global optimum as compared to the basic GA. From the simulated results obtained, it is clear that HVDC-ED has a better ability to control power flow, decreased transmission line losses and an increased capability maintain voltage stability especially for bulk power transmission over the long transmission lines. This compensates for the high costs of the HVDC as compared to the high voltage alternating current (HVAC) in the applications where bulk power is being transmitted over long distances.**

Key Words: Economic Dispatch(ED), High Voltage Direct Current (HVDC), Improved Genetic Algorithm (IGA)

INTRODUCTION

Based on the nature of current, there are two types of power electric power transmission lines HVAC and HVDC lines. HVDC system therefore, involves transmission of power at high voltages using direct current transmission lines with the aim of improving system efficiency and reducing energy cost. It has zero-frequency, implying that voltage and current do not change direction as energy is transmitted and its transmission is associated with Active power flow. On the other hand, the HVAC system involves transmission of power at high voltages using alternating current transmission lines. In this case, both the voltage and current on the transmission line move in a wave-like pattern and are continually changing direction 50 Hz or 60 Hz. Its transmission is associated with both active and reactive power flow. Wind and Solar sources integrated to the grid can be located very far from the consumers, hence the need to generate power in AC, transmit in HVDC and consume as AC [1,2].This paper therefore focusses on the economics of HVDC transmission, that is, HVDC-ED.

Thomas Edison installed the first central electric station in New York in 1882 which operated at 110V DC. However, AC lines replaced almost all DC lines due to their ability to use transformers for transmitting power over longer distances and at higher voltages. This gave rise to HVAC systems [3,4].Later on, development of high voltage valves made it possible to once again transmit DC power at high voltages and over long distances, giving rise to HVDC transmission systems. Although the HVDC system proved to be a technical reality, there still remained uncertainty as to whether it could compete in practice and be economically viable as compared to HVAC and load flow studies [5]. The HVDC transmission system is a high power electronics technology used in electric power systems mainly due to its capability of transmitting large amounts of power over long distances with minimal losses. Overhead lines or underground/submarine cables can be used as the transmission path.

Past researches have considered ED for HVAC at quite a broad extend. However, with the growing use of HVDC lines, there is need to consider HVDC-ED which involves the allocation of generation levels to generating units in a power system with HVDC lines so that the system load is served entirely and most economically while considering operational limitations of the HVDC transmission and generation facilities. DC system constraints are introduced by use of DC transmission lines parameters. This paper has thus formulated ED for HVDC for the first time, and a heuristic method called Improved Genetic Algorithm (IGA) has been applied to validate the formulation.

LITERATURE REVIEW

A:HVDC Basics

The three main elements of a HVDC system are the converter station at the transmission and receiving ends, the transmission medium and the electrodes[8].The converter stations at each end are replicas of each other and therefore consist of all the needed equipment for going from AC to DC or vice versa. The main components of converter stations are converter transformers, thyristor valves, VSC Valves, DC filters, AC filters and capacitor banks [8].Conversion of electrical current from AC to DC using a rectifier at the transmitting end, and from DC to AC using an inverter at the receiving end is the fundamental process that occurs in a HVDC system. Two basic converter technologies used in modern HVDC transmission systems are traditional/classical line commutated current source converters (CSCs) and self-commutated voltage source converters (VSCs).

HVDC configurations can be used for both VSC and CSC converter topologies and are classified into monopolar, bipolar and homopolar [9,16].The monopolar link has only one conductor and the ground serves as the return path. The link normally operates at negative polarity as there is reduced radio interference and less corona loss. This configuration is usually preferred in the case of cable transmissions with submarine connections. The bipolar links have two conductors, one operating at positive polarity and the other operating at negative polarity. The advantage of this configuration is the fact that one of the poles can continue to transmit power as a monopolar link with a ground return path if the other link is out of service. Theoretically, the ground current is zero in the case of this configuration since both poles operate with equal current. This is the most common configuration for modern HVDC transmission lines.The Homopolar links have two or more conductors having the same polarity (usually negative) and always operate with ground or metallic path as return. This configuration is not being used recently.

B:Need for HVDC

The electric power grid is experiencing increased needs for enhanced bulk power transmission capability, reliable integration of *large-scale renewable energy sources*, flexible power flow controllability and interconnections between asynchronous AC networks around the world. However, it has become a challenge to increase power delivery capability and flexibility with conventional AC expansion options in meshed, heavily loaded HVAC networks. As such, upgrading electric power grids with advanced transmission technologies such as HVDC systems becomes more attractive in many cases so as to achieve the needed capacity improvement while satisfying strict environmental and technical requirements[10]

Applications of HVDC transmission include long distance bulk power transmission by overhead lines, underground or underwater cables, interconnection of AC systems operating at different frequencies, the back-to-back HVDC coupling of stations, the multi-terminal DC(MTDC),the asynchronous interconnections between three or more AC networks and finally, the control and stabilisation of power flows in AC interconnections of large interconnected systems[16].It is indisputable that generation by AC, transmission by DC and distribution by AC are the most economical aspects of economic power dispatch that cannot be ignored. Thus, AC and DC are complementary

For optimal design of a HVDC transmission system, many factors need to be considered which include power capacity to be transmitted, type of transmission medium, distance of transmission, voltage levels, temporary and continuous overload, status of the network on the receiving end, environmental conditions and other safety and regulatory requirements. However it's still difficult to attach a price tag on the cost of a HVDC system. Thus, ED for HVDC systems has not been formulated so far,this forms the basic objective of this paper [10].

The choice of DC transmission voltage level has a direct impact on the total installation cost. At the design stage, an optimisation is done finding out the optimum DC voltage from investment and losses point of view. In the evaluation of losses, the energy cost and the time horizon for utilisation of the transmission have to be taken into account. Finally the depreciation period and desired rate of return (or discount rate) should be considered. Therefore, to estimate the costs of an HVDC system, it is recommended that life cycle cost analysis is undertaken [11]

One great challenge in economic transmission planning is to quantify the benefits of a transmission upgrade project and to accurately evaluate the economic impacts. To evaluate the economic impact of a transmission project, it is necessary to quantify if the proposed project leads to more efficient ED, eliminates transmission bottlenecks and brings economic benefits to the consumers in the markets [11].This paper forms a benchmark towards the achievement of this goal.

C:HVDC Vs HVAC

HVDC transmission can be compared with the HVAC transmission basically from two points of view, the technical and the economic points of view respectively. These are discussed briefly in the next subsections .It should be noted however that the economic comparisons are of interest in this paper.

Technical Comparisons

HVDC transmission overcomes some of the technical problems which are usually associated with the HVAC transmission. These include interconnection of asynchronous networks, congestion management, submarine and underground power transmission, reduction of skin effect, power flow control, stability analysis and connecting a remote generating plant to the distribution grid [12, 16].

Economic Comparisons

In terms of economics, HVDC is suitable for bulk power delivery over long distances at reduced cost due to reduced number of conductors and insulators, reduced ROW hence little environmental impact, and allows reserve sharing at increased efficiency. Also, HVDC uses light and cheap towers and there is less phase-to-phase and phase-to-ground clearances. In the Bipolar links there is reduced power loss as there are two conductors. The HVDC have bundled conductors leading to reduced corona losses[16].

The total capital cost of a transmission system must be equal to the sum of the capital cost of the substations plus the capital cost of the lines.The variation of total costs for HVAC and HVDC as a function of line length is as shown in Figure 1.0 and 2.0. As illustrated, there is a break-even distance beyond which the total costs of the DC option will be lower than the

AC transmission option. The break-even distance depends on several factors such as transmission medium cable or OH line and different local aspects such as permits, cost of local labour etc. For overhead lines it's in the range of 500 to 900 km, for submarine cables between 25 and 50 km and twice as far for underground cables [16] .

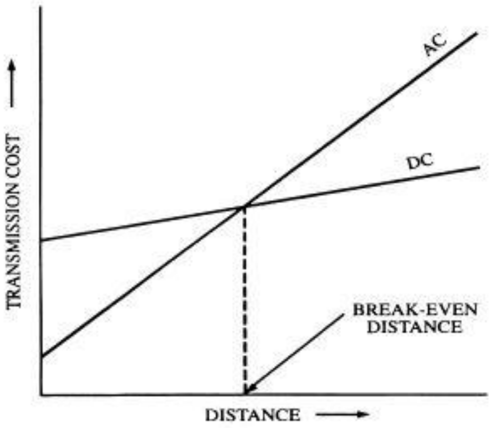


Figure 1.0 : Transmission cost as a function of line length for both an AC and DC system. [16]

The investment costs for HVDC converter stations are higher than for HVAC substations. However, the costs of transmission medium overhead lines and cables), land acquisition/right-of-way costs operation and maintenance costs are lower in the HVDC case. Moreover, Initial loss levels are higher in the HVDC system, but they do not vary with distance, In contrast with HVAC system where loss levels increase with distance [16].

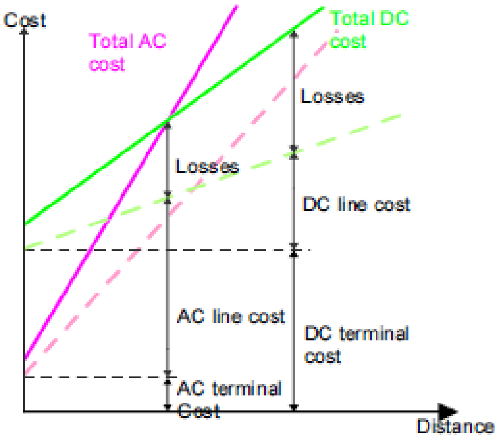


Figure 2.0: Cost breakdown with and without considering losses [16]

Based on the latest research and developments, HVDC systems offer many promising technical and economic benefits thus is a promising approach to best utilizing transmission grid for maximized social welfare. However, major technology breakthroughs are required to overcome problems inherent in HVDC systems such as; increased cost of converter stations, problem of circuit breaking, HVDC system control, effective cooling voltage transformation challenge, reactive power requirement and the generation of harmonics[12,16].

D..East Africa HVDC Interconnection

Kenya's geographical position makes it an ideal hub for regional power interconnections in the Eastern Africa region. In this connection, we have the proposed 1045km, Eastern Africa Interconnector (Ethiopia – Kenya Line), 500kV, HVDC bipolar transmission line and a 400kV sub-station [6]. KETRACO will construct over 4,000 Km of high voltage transmission infrastructure comprising of lines, switch gears and sub-stations across the country over the next 3-4 years. The project demands high standards, both technically, economically and logistically. This means that the HVDC transmission line will have a length of more than 1,000 km and will be awarded in 5 single lots. Another lot will entail both the converter stations from 400 kV AC to 500 kV DC, the related 400 kV switchgears in 1.5 circuit breaker configuration, two ground electrodes, as well as the connection of the 400 kV switchgears to the national energy supply networks. The proposed 500 kV HVDC line with a power transfer capacity of 2000MW will originate from Wolayta-Sodo in Ethiopia and terminate at Suswa in Kenya, which is a connection point for the Lake Turkana Wind Power Project (LTWPP).Hence, the wind power economics are closely associated with the HVDC-ED results,hese forms the generation and transmission power economics which are key in power system planning, operation and control.The total length of the proposed transmission line is approximately 1045 km, out of which approximately 433 km will be in Ethiopia and 612 km in Kenya [7].

E:Problem Statement and Formulation

The objective of the classical economic dispatch is to minimize the total system fuel cost by adjusting the power output of each of the generators connected to the grid [13].On the other hand, dynamic economic dispatch (DED) considers change-related costs. It is the most recent formulation that represents a real time power system. The DED takes the ramp rate limits, valve points and prohibited operating zone of the generating units into consideration. The general form of DED for HVAC was formulated by Yusuf Somez, 2013[13] and is given by

$$\mathrm{F}(P_{ij}) = \left\{ a_{0,i} + \sum_{j=1}^{L=N_G} a_{ji}\, P_{t,i}^{j} + r_i \right\} + \left| e_i \sin f_i (P_i^{min} - P_i) \right|$$

Subject to

$$\sum_{i=1}^{NG} P_{gi} = P_D + P_L$$

$$P_i^{min} \leq P_i \leq P_i^{max}$$

$$P_{ij} - P_{ij-1} \leq UR_i$$

$$P_{ij-1} - P_{ij} \leq DR_i$$

$$-P_l^{max} \leq P_{lj} \leq P_l^{max} \quad l = 1,2,3 \ldots \ldots L$$

$$P_i \leq P^{PZ,LOW}$$

$$P_i \geq P^{PZ,HIGH}$$

Nowadays, power electronic devices are utilized in the electric power system, such as the HVDC and FACTS. They provide more controllability of the system by supplying more decision variables of OPF. By adjusting these decision variables, an optimized system operation state will be achieved. On the contrary, State variables are usually the bus voltage and transmission line current among others. All these state variables change with the change of decision variables based on the laws of physics such as ohm's law [4, 5].

Transmission losses may be neglected when distances are very small but in a large interconnected network where power is transmitted over long distances, transmission losses are a major factor and affect the optimum dispatch of generation. In this paper, modified B-coefficients of loss transmission formula that cater for DC systems have been used to account for system losses. In addition the cost coefficients for the equivalent AC system have been adopted. Due to the absence of inductance, the voltage drop in a D.C. transmission line is less than that in the A.C. line for the same load and sending end voltage. Although HVDC incurs power losses during the conversion and inversion process, line losses in HVDC are smaller than HVAC especially when used over long distances, which thus compensate for the high conversion losses. Typically, overall losses in HVDC transmission are 30-50% less than HVAC transmission. In this paper, HVDC systems have been considered to have a 40% less loss than HVAC. System losses can also be determined exactly as a result of solving the power flow problem [7].

It should be noted that in HVDC the inequality constraints are usually the operation or physical limits. For example, transmission line capacity is constrained by its thermal limit, the bus voltages are within their insulation limits and generating units have lower $(P_{Gi\,min})$ and upper $(P_{Gi\,max})$production limits that are directly related to the machine design [3].These constraints restrict the ED of the generators to a range between the maximum and minimum values. They include the following:

The power generator capacity constraint.

$$P_{Gi\,min} \leq P_{Gi} \leq P_{Gi\,max}$$

Tap ratio of the converter.

$$T_{min} \leq T \leq T_{max}$$

Ignition angle of the converter.

$$\alpha_{min} \leq \alpha \leq \alpha_{max}$$

Extinction angle of the converter.

$$\Upsilon_{min} \leq \Upsilon \leq \Upsilon_{max}$$

DC current.

$$I_{dc\,min} \leq I_{dc} \leq I_{dc\,max}$$

DC voltage.

$$V_{min} \leq V \leq V_{max}$$

METHODOLOGY

A:ED -HVDC using IGA

Genetic Algorithm (GA) is based on the evaluation of a set of random solutions called population. The starting population represents a gene pool whose all elements are formed at random. A large population size is chosen for the conventional GA while a smaller population is chosen for the Improved GA (IGA). Each individual in the population is called a chromosome and it represents a potential solution to the problem. The chromosomes in this paper are the power outputs of the generators (PGi) and they evolve through successive iterations called generations. During each generation, the chromosomes are evaluated using some fitness function [14]. The fitness function for the fuel cost minimization is given by;

$$Fitness = \frac{1}{Ft}$$

where Ft is the total fuel cost ($/hr).

The fittest individuals are those with the lowest cost of fuel and lie within the given constraints. Fitness function is thus used to transform the objective function value into a measure of relative fitness.

For the HVDC-ED problem, in order to minimize the total operating cost of a power system while meeting the total load plus transmission losses within generator limits, the fuel cost function is evaluated subject to the HVDC and HVAC constraints. The objective function is thus used to provide a measure of how individuals have performed in the problem domain.

To create the next generation, new chromosomes called offsprings are formed by using GA operators and are selected using the Roulette Wheel Technique according to the value of fitness function. A crossover operator with a crossover probability (Pc) of 0.8 is chosen and is responsible for producing new chromosomes that are different from the parent's characteristics. The crossover probability (Pc) affects the rate at which the process of crossover is applied. A mutation operator is used to inject new genetic material into the population by randomly altering each gene with a small probability (Pm) of 0.001. Pm is the probability with which each bit position of chromosome in the new population undergoes a random change after the selection process. The GA process repeats until the specified maximum number of generations is reached.

The search for a global optimum to an optimization problem is thus conducted by moving from an old population of individuals to a new population using GA operators and hence the problem to be represented in the IGA must be carefully designed so as to utilize the GA's ability to efficiently transfer information between chromosomes (strings) and the problems objective function.

In this paper, a Micro-GA (MGA) has been used as the IGA and it features several characteristics compared to a Conventional GA [14].MGA exhibits superior performance in terms of optimal generation allocations, it involves a relatively small population size of individuals which is processed by the three GA operators with the mutation rate fixed at a very small value. Further the method avoids premature convergence by frequent call of a “start and restart” procedure through which a diversity of the population string is introduced. Lastly, it exhibits faster computational time unlike the conventional GA which has a large number of function evaluations.

B: Parameter representation

Binary representation is usually applied to power optimisation problems, however in this paper, Real Coded GA (RCGA) is used which is a MGA employing real valued vectors for representation of the chromosomes. The use of RCGA has several advantages in optimization over binary encoding. First, there is no loss in precision by discretisation to binary or other values. Also, less memory is required as efficient floating-point internal computer representations can be used directly. Further, efficiency of the GA is increased as there is no need to convert chromosomes to binary type. Lastly there is greater freedom to use different GA operators.

Use of the RCGA requires use of new crossover and mutation operators. For crossover, non-uniform arithmetic crossover is used where two parent chromosome Vectors are combined linearly to produce two new offspring variables according to the following equations:

$$Offspring\ 1 = \alpha ma + (1-\alpha)pa$$

$$Offspring\ 2 = (1-\alpha)ma + \alpha pa$$

where α - a random number in the interval [0, 1] and Ma and Pa are the nth variable in the mother and father chromosome respectively.

For mutation, non-uniform mutation is used where the genes to be mutated are selected randomly then the new gene is obtained as:

$$PGnew = \alpha(PGmax - PGmin) + PGmin$$

The variables to be optimized are the power outputs of the generators. For Real valued representation, the nth chromosome Cn can be defined as an array with 1*N elements as :

$$Cn = [PG1, PG2, \ldots\ldots\ldots\ldots PGn]$$

where n is the population size and PGi is the generation power of the ith unit at nth chromosome. The IGA parameters used in this paper are as shown in Table 1.0

Table 1.0: IGA Parameters

Population size	50
No. of iterations	100
Crossover probability	0.80
Mutation probability	0.001

C: Pseudo Code for IGA

The steps involved in solving the IGA are as follows:

Step 1. Initialization. Initialize population size (n), Crossover Probability (Pc), Mutation Probability (Pm), number of iterations and read input data i.e. HVDC cost coefficients, power demand, generation unit minimum and maximum real power constraints,ramp rsates and valve points.

Step 2. Formation of population. Create the initial population randomly of size, n, using a random number generator within a feasible region.

Step 3. Evaluate the fitness function. Establish the fitness of each chromosome in the population using equation (15) then sort the fitness obtained in descending order. Chromosomes having a higher value of fitness infer lowest cost function and thus are selected for the next generation. The average fitness of the population is also calculated.

Step 4.Check convergence. Check whether the number of iterations reaches the maximum. If the number of iterations reaches the maximum, and there is no any generator power violation stop and output the results otherwise increment the iteration numbers and go to Step 5.

Step 5. Apply genetic operators. Parent individuals are selected using Roulette Wheel selection procedure followed by crossover and finally mutation operator is used for regaining the lost characteristics during the process. Create a new population of offsprings and apply elitism preserve strategy. For the CGA go to step 3 but for MGA [IGA], the genotype convergence is first checked then application of the restart mechanism and finally looped back to Step 3. The flow chart for the MGA is as shown in Figure 1.0

RESULTS AND ANALYSIS

A: Modified IEEE 9 Bus System HVDC

An IEEE 3 generator 9 bus system has been used to verify the effectiveness of the IGA ED for HVDC system and the results obtained compared with those for a HVAC system.The network is as shown in Figure 3.0.

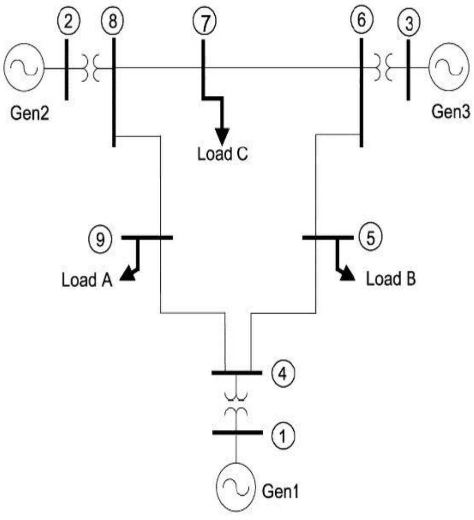
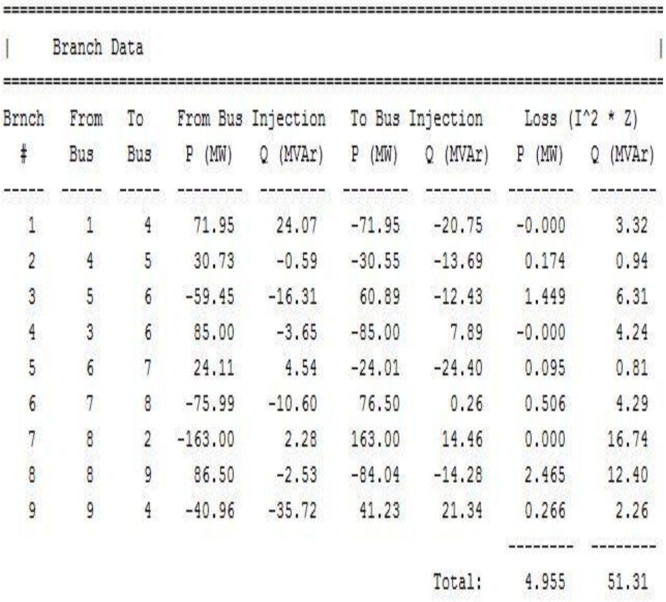


Figure 3.0: IEEE 9 Bus System

The HVAC branch data for the IEEE 9 Bus System is as shown in Table 2.0. The modified HVDC branch information that has been generated in this paper is as shown in Table 3.0.From this table it is clear that HVDC leads to a reduction of both real and reactive power losses.HVDC The modified cost coefficients are as tabulated in Table 4.0.Further,the DC link characteristics and results are as in Table 5.0 and Table 6.0 respectively.

Table 2.0: HVAC Branch data of an IEEE 9 bus system



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================================================================================
|     Branch Data                                                              |
================================================================================
Brnch   From   To    From Bus Injection   To Bus Injection     Loss (I^2 * Z)
  #     Bus    Bus    P (MW)   Q (MVAr)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
-----  -----  -----  --------  --------  --------  --------  --------  --------
   1      1      4     71.95     24.07    -71.95    -20.75    -0.000     3.32
   2      4      5     30.73     -0.59    -30.55    -13.69     0.174     0.94
   3      5      6    -59.45    -16.31     60.89    -12.43     1.449     6.31
   4      3      6     85.00     -3.65    -85.00      7.89    -0.000     4.24
   5      6      7     24.11      4.54    -24.01    -24.40     0.095     0.81
   6      7      8    -75.99    -10.60     76.50      0.26     0.506     4.29
   7      8      2   -163.00      2.28    163.00     14.46     0.000    16.74
   8      8      9     86.50     -2.53    -84.04    -14.28     2.465    12.40
   9      9      4    -40.96    -35.72     41.23     21.34     0.266     2.26
                                                             --------  --------
                                                    Total:     4.955    51.31
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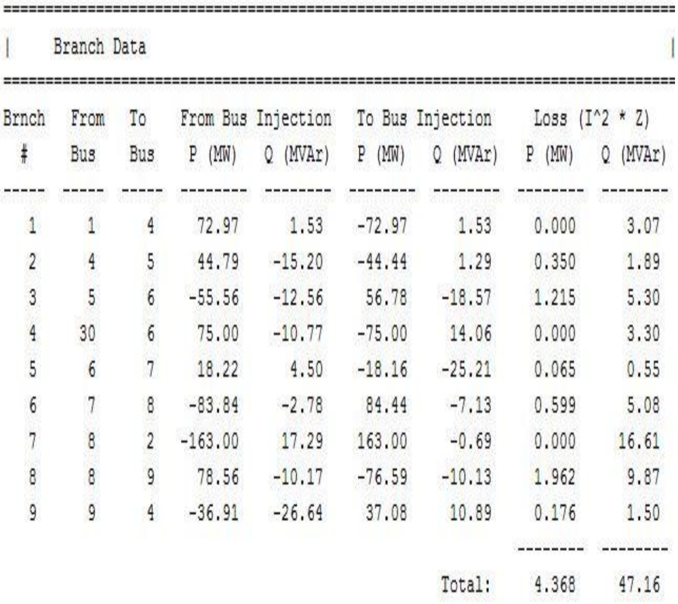
Table 3.0 : HVDC Branch data of an IEEE 9 bus system



```
================================================================================
|     Branch Data                                                              |
================================================================================
Brnch   From   To    From Bus Injection   To Bus Injection     Loss (I^2 * Z)
  #     Bus    Bus    P (MW)   Q (MVAr)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
-----  -----  -----  --------  --------  --------  --------  --------  --------
   1      1      4     72.97      1.53    -72.97      1.53     0.000     3.07
   2      4      5     44.79    -15.20    -44.44      1.29     0.350     1.89
   3      5      6    -55.56    -12.56     56.78    -18.57     1.215     5.30
   4     30      6     75.00    -10.77    -75.00     14.06     0.000     3.30
   5      6      7     18.22      4.50    -18.16    -25.21     0.065     0.55
   6      7      8    -83.84     -2.78     84.44     -7.13     0.599     5.08
   7      8      2   -163.00     17.29    163.00     -0.69     0.000    16.61
   8      8      9     78.56    -10.17    -76.59    -10.13     1.962     9.87
   9      9      4    -36.91    -26.64     37.08     10.89     0.176     1.50
                                                             --------  --------
                                                    Total:     4.368    47.16
```

Table 4.0 : Generator Data for modified IEEE 9 bus system

Generators	PGi min MW	PGi max MW	ai $/MW2	bi $/MW	Ci $
1	90	250	0.012	20	400
2	10	300	0.010	10	200
3	10	270	0.015	12	150

Table 5.0: DC Link Characteristics [15]

	Rectifier	Inverter
Bus Number	5	4
Commutation Reactance	0.126	0.0725
Minimum Control Angle	7	10
Number of Tap Position	27	19
Resistance of DC Line	0.00334	
DC Power Flow Setting	0.587	
Inverter End DC voltage	1.284	

Table 6.0: DC Link 5-4 Results [15]

	Rectifier	Inverter
DC voltage	1.2855	1.2840
Transformer tap position	0.9707	0.9565
Control Angles	1.5542	1.5546
Real power flow	0.586	0.585
Reactive power flow	0.0206	0.5952
Power factor	0.935	0.978
Current in DC link	0.4562	

B:Optimal Power Generation using OPF and IGA

A DC link model has been integrated with standard AC load flow program and also a dispatch carried out. The optimal generation and cost of the three generating units is shown for power demands of 300MW, 450MW and 565 MW. From Tables 7.0 and 8.0 it's evident that IGA is better than OPF in optimal power generation and costing. That is,IGA led to reduced losses and reduced fuel cost with increasing demand as compared to the OPF.

Table 7.0: Optimal Power Generation for a 3 generator unit using IGA

Power Demand(MW)	P1	P2	P3	P_L	Total fuel cost($)
300	90.23	187.66	27.65	5.542	5224.30
450	90.47	300	77.04	17.510	7512
565	140.3	300	165.35	40.712	10,088

Table 8.0: Optimal Power Generation for a 3 generator unit using OPF

Power Demand(MW)	P1	P2	P3	P_L	Total fuel cost($)
300	90.00	82.85	128.35	1.200	5763.08
450	90.00	158.20	206.04	4.241	8769.67
565	90.00	234.6	244.69	4.307	11379.34

C: HVDC and HVAC Comparisons

The comparison of HVAC and HVDC is a shown in tables 9.0-11.0 with increasing demand. From Tables 9.0 -11.0, it is observed that values obtained for ED using IGA resulted to lower fuel cost as compared to those of OPF using Newton Raphson method. However, system losses in HVDC-ED are less than in HVAC-ED as expected.

Table 9.0: Comparison of Power Generated between HVDC & HVAC (PD= 300MW)

Generator No.	HVDC (OPF)	HVDC (IGA)	HVAC (IGA)
P_1(MW)	90	90.23	125.76
P_2(MW)	82.85	187.66	112.33
P_3(MW)	128.35	27.65	73.14
Total Power Generated(MW)	301.20	305.54	311.23
P_{LOSS} (MW)	1.200	5.542	11.23
Total fuel cost($)	5763.08	5224.30	3484.71
Convergence time(Sec)	0.20	1.5316	1.64

Table 10.0: Comparison of Power Generated between HVDC&HVAC (PD= 450MW)

Generator No.	HVDC (OPF)	HVDC (IGA)	HVAC (IGA)
P_1(MW)	90	90.47	187.73
P_2(MW)	158.20	300	171.85
P_3(MW)	206.04	77.04	115.93
Total Power Generated(MW)	454.24	467.51	475.51
P_{LOSS} (MW)	4.241	17.51	25.51
Total fuel cost($)	8769.67	7512	4885.95
Convergence time(Sec)	0.10	1.9155	1.60

Table 11.0: Comparison of Power Generated between HVDC& HVAC (PD= 565MW)

Generator No.	HVDC (OPF)	HVDC (IGA)	HVAC (IGA)
P_1(MW)	90	140.37	238.71
P_2(MW)	234.62	300.00	215.36
P_3(MW)	244.69	165.35	151.75
Total Power Generated(MW)	569.31	605.71	605.82
P_{LOSS} (MW)	4.307	40.712	40.82
Total fuel cost($)	11,379.34	10,088	6029.56
Convergence time(Sec)	0.09	1.9250	2.04

The Power losses (both real and reactive) are as shown in Table 12.0. In this case, a system with HVDC links results in reduced losses at all demands.

Table 12.0: Comparison of Losses

		WITH HVDC	WITHOUT HVDC
LOSSES	Real Power(MW)	4.368	4.955
	Reactive(MVAR)	47.16	51.31
Convergence Time (Sec)		0.12	0.11

Fitness of IGA as a function of the power generation is as shown in Figure 4.0.From this figure, the system is seen to converge on the 51st iteration.

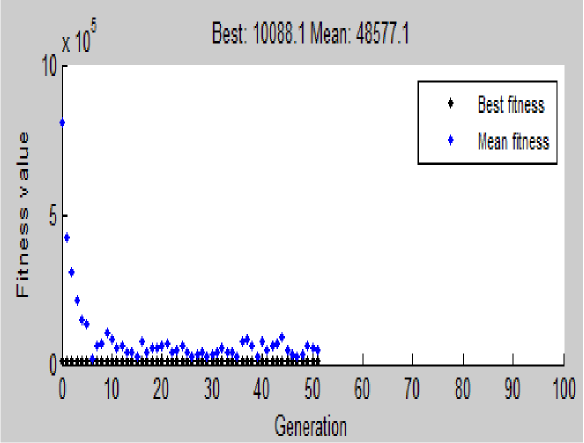


Figure 4.0: HVDC-ED Solution Convergence

It evident from Table 12.0 and Figures 5.0-7.0 that active and reactive power losses of a power system with HVDC links are less than those with purely HVAC links. This is because the DC link has more capacity for active power transfer in comparison to the AC line which transports a considerable amount of reactive power. However, the resulting use of HVDC links results to an increased number of iterations and consequently more convergence time.

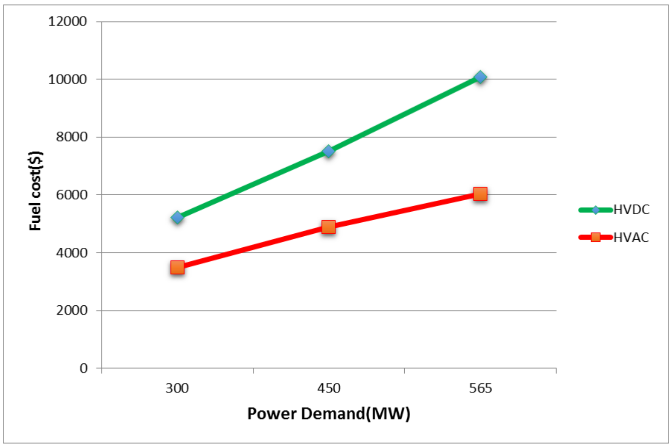


Figure 5.0: Fuel cost against Power demand

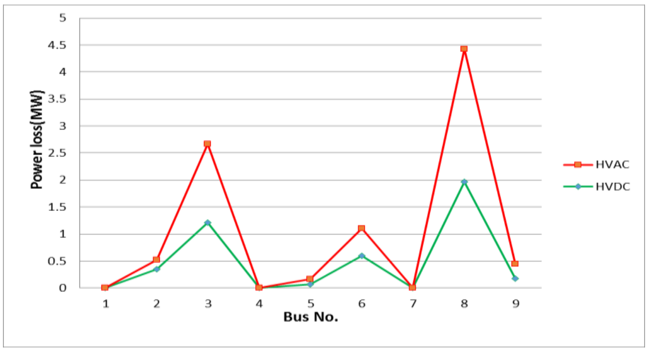


Figure 6.0: Comparison of HVDC vs HVAC Real Losses

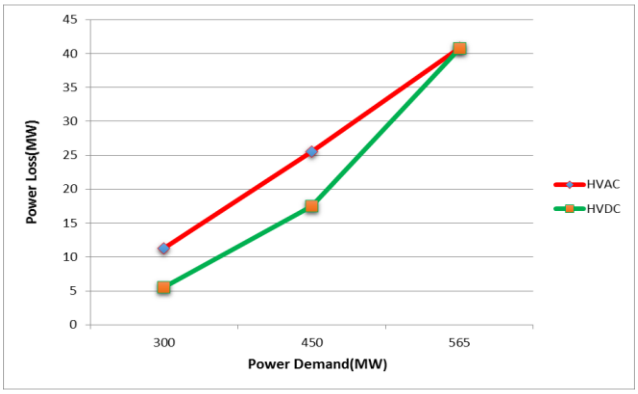


Figure 7.0: Relation between power demand and system losses

The cost of generation is observed to increase with increase in power demand. This is as shown in Figure 4.0. However, generators tend to operate close to their power constraints; power output is near the minimum or maximum limits. For instance from, Table 9.0, P_1=90.23MW yet $Pg_{(min)}$ = 90MW similarly in Table 10.0, P_2=300MW yet $Pg_{(max)}$ =300MW. The HVDC and HVAC comparison in Tables 9.0 – 11.0 shows that the cost of generation in HVDC is higher than in HVAC but the resulting power loss is relatively lower in the HVDC.

D:Voltage profile in HVDC and HVAC

Characteristic of the HVDC system to provide voltage stability is evident from Figures 8.0-10.0. Compared to the HVAC line, the effect of HVDC on system voltage is lower, and presents a voltage profile within the allowable limits, close to unity. From published works, voltage stability of a congested line can be achieved by converting the HVAC line to an HVDC. For instance voltage magnitude at a congested HVAC bus 5 is 0.9755; in this work voltage magnitude at bus 5 is 1.Congestion relieve is thus achieved by converting line 4-5 from AC to a DC line and hence controlling power flow resulting to more of the cheaper generation being dispatched.

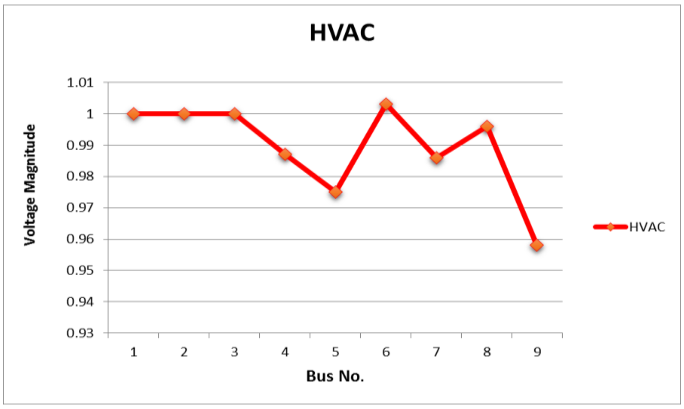


Figure 8.0: Voltage profile for an HVAC

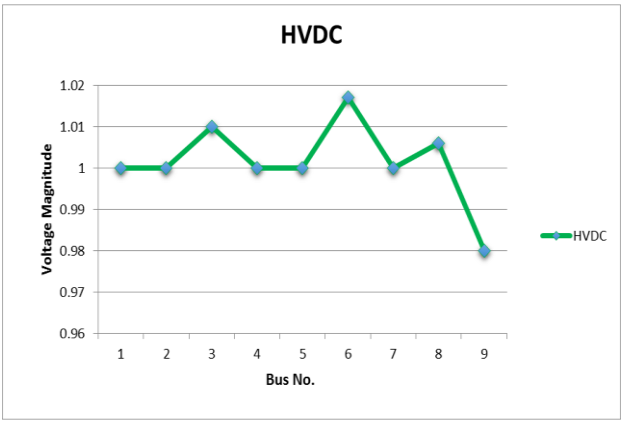


Figure 9.0: Voltage profile for an HVDC link.

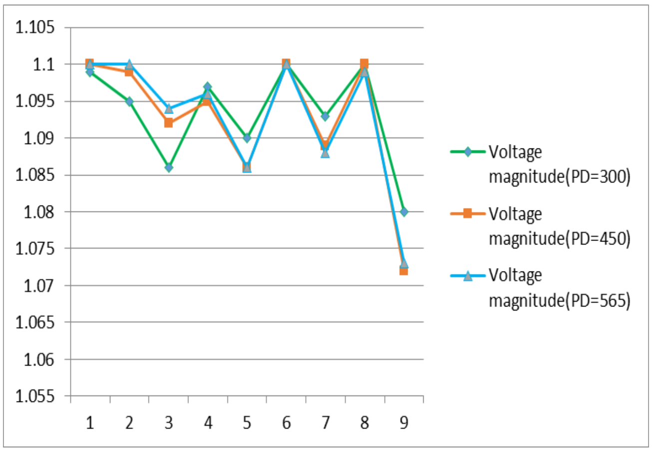


Figure 10.0: Voltage magnitudes for various demands

CONCLUSION AND RECOMMENDAtions

The objective of this paper was to obtain HVDC-ED . A real coded micro GA[MGA] has been used to allocate real power to generating units while adhering to system constraints so as to minimize fuel cost and meet load demand. Data from IEEE 3 generator, 9 bus system has been used and the algorithm implemented in Matlab environment. GA is preferred for its ability to converge in global maxima. ED for a HVDC system was found to increase the generation cost but decrease the real power losses. From the obtained results, it's clear that the proposed HVDC system has better ability to control power flow, decrease the transmission line losses and maintain voltage stability.

Although the focus of the paper is on HVDC-ED, areas such as HVAC,optimal power flow and load flow analysis were briefly covered so as to gain a better understanding of the operation of the HVDC system. Load flow analysis has a great importance in future expansion planning, in stability studies and in determining the best economical operation for existing systems.

The main challenge encountered carrying out this research work contained in this paper is that little research has been done regarding the impact of HVDC systems on the ED. However, it was successfully proven that although the cost for HVDC systems are high, the long term benefits in terms of efficiency and reliability are large enough to justify this high cost as compared to a HVAC system for bulk power transmission.

Further studies are needed for a complete investigation of the impact of HVDC systems on ED. For instance, incorporation of multiple DC lines to AC systems. AC systems provide flexible access to generation sources and loads alike. Thus, conversion of congested AC lines to DC lines so as to improve flow control on both the converted line and the remaining AC system should decrease the dispatch cost through congestion relief. Also Security constrained economic dispatch (SCED) for a HVDC system need to be investigated so as to better analyse the ability of a HVDC system to control and stabilize power. Lastly, there is need to consider a mechanism for dispatch cost improvement via an HVDC system using the more accurate cubic cost functions.

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