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# Application Of A Novel Cheetah Optimization Algorithm For Conductor Placement In Hybrid Transmission Corridors: Addressing Field Effects And Structural Design Constraints

**Mr. Manan Pathak[1*], Dr. Dishang Trivedi[2]**
[1*]Research Scholar, Gujarat Technological University Ahmedabad, Gujarat, India
[2]Deputy Director, Commissionerate of Technical Education, Gujarat Former, Associate Professor, Department of Electrical Engineering, LD College of Engineering, Ahmedabad, Gujarat, India

***Abstract:***
*The Indian power sector is rapidly expanding, relying on both Extra High Voltage Alternating Current (EHVAC) and High Voltage Direct Current (HVDC) transmission lines to meet growing electricity demands, especially for long-distance bulk power transfer. Optimizing hybrid systems combining EHVAC and HVDC is crucial for efficiency, stability, and cost reduction. Paper is on formulating an objective characteristic to optimize hybrid AC-DC transmission lines, deliberating the influences of electrical and magnetic fields, along with corona-brought on audible noise and radio interference. A new multi-goal characteristic has been evolved to simultaneously lessen electromagnetic discipline exposure by optimizing conductor configurations for each single-circuit and double-circuit hybrid transmission line. The Cheetah Optimization Algorithm (COA) addresses this constrained multi-objective trouble, assuring adherence to minimum electrical clearance standards and attaining the highest quality conductor arrangement that reduces electromagnetic area emissions. The effects of this optimization are corroborated via comparison evaluation with analogous studies completed in different international locations at one-of-a-kind voltage ranges, enhancing the validity and application of the proposed optimization method for hybrid EHV/UHVAC–HVDC transmission structures. The Cheetah Optimization Algorithm, a nature-inspired metaheuristic, shows promise in such optimization tasks, but its specific application to these hybrid systems in India requires further exploration.*

## INTRODUCTION:

India's power sector, with its uneven distribution of energy resources, benefits from robust transmission systems, including HVDC for long distances. While specific studies on the Cheetah Optimization Algorithm for EHVAC-HVDC hybrid lines in India were not found, its capabilities align with the sector's needs. The algorithm could help optimize hybrid systems by addressing challenges like transmission congestion and load balancing, as seen in general power system optimizations.

Background on Optimization in Power Transmission: Optimization, in general, refers to the process of enhancing something to achieve better outcomes. This can involve minimizing undesirable aspects, such as costs or losses, or maximizing beneficial features, such as efficiency, durability, or overall performance. The result of optimization typically yields an improved state compared to the original conditions before the optimization algorithm was applied. In any given process, a set of inputs is processed and transformed into outputs that meet the expected objectives. Optimization algorithms are essential in power system planning, helping to minimize costs, reduce losses, and enhance reliability. While various methods like genetic algorithms and particle swarm optimization are commonly used, the Cheetah Optimization Algorithm, inspired by cheetah hunting strategies, is noted for handling large-scale optimization problems. Its application in Economic Load Dispatch, which considers transmission losses, suggests potential for transmission line optimization.

**Generic Parameters for Hybrid Model Optimization in Transmission Line**

To improve power switching quality and performance, an effort is directed towards the Cheetah Optimization Search Algorithm (COA) [40]. COA is an operating meta-heuristic algorithm which uses a population-based approach. As COA has the potential of copying the hunting behaviour of the cheetah in the case of our study, it is most likely to have a better performance compared to other algorithms like PSO, HBO, and Wild Horse Optimization (WHO). Cheetah is famous for its very high speed and agility, which allows to explore solution space rapidly, therefore leading to potentially faster convergence compared to PSO, HBO and WHO. In addition, it is an extremely adaptive system because of changing environmental constraint and conditions, akin to how the cheetahs change their hunting strategy on behaviour of preys. In addition, the adaptability makes the algorithm more effective to explore the complex solution landscape. In addition to COA's population-based approach, the collective intelligence realized provides superior means for the exploration and exploitation of solution space and in turn, better ability to discover optimal solutions in various domains. The sum of speed, adaptability, population-based methodology, efficient; explanatory; exploitation, robustness to constraints and final empiric test, compose themselves to a good performance of COA as a transmission hybrid lines implementer with multiple constraints.

**Detailed Analysis of Cheetah Optimization Algorithm in EHVAC-HVDC Hybrid Transmission Line Optimization for the Indian Power Sector**

The Indian power sector is undergoing significant expansion to meet the rising electricity demand, driven by economic growth and population increase. Transmission infrastructure plays a pivotal role, with both Extra High Voltage Alternating Current (EHVAC) and High Voltage Direct Current (HVDC) systems being integral. EHVAC is traditionally used for shorter distances with lower losses, while HVDC is preferred for long-distance, high-capacity transmission due to lower electrical losses and the ability to connect asynchronous grids. Hybrid systems, combining EHVAC and HVDC, are emerging to leverage the strengths of both, particularly in India's diverse geographical and energy resource landscape.

**Cheetah Optimization Algorithm: Overview and Capabilities:**

The COA, first detailed in a 2022 study published in *Scientific Reports* (The cheetah optimizer: a nature-inspired metaheuristic algorithm for large-scale optimization problems), mimics cheetah hunting behaviours to solve optimization challenges. It incorporates strategies like "leave the prey and go back home" to enhance population diversification, convergence performance, and robustness. The algorithm has been tested on benchmark functions (e.g., CEC-2005, CEC2010, CEC2013) and applied to engineering problems, notably the Economic Load Dispatch (ELD) problem in power systems.

The flowchart illustrating the COA process is presented in Fig. 2.

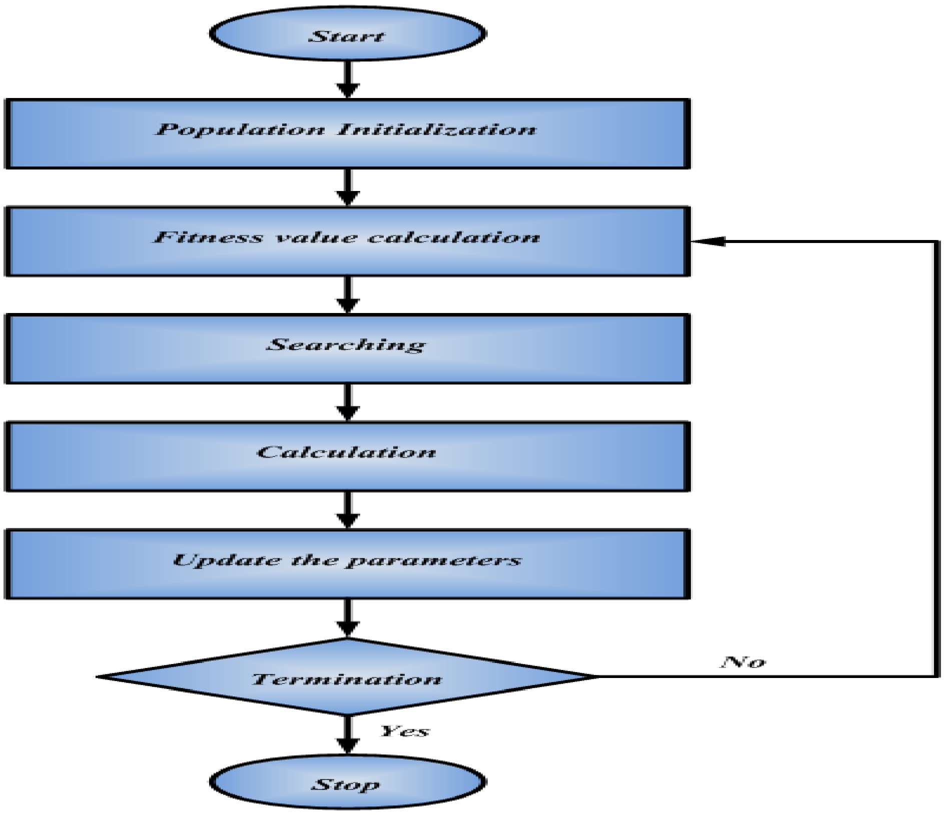



**Figure: Basic Flow Chart of the Cheetah Optimization Search Algorithm (COA) Process**

Step 1: Initialization

Initiate the input-parameters such as voltage, current, Power, Conductor type, Conductor size etc.

Step 2: Random-Generation

After the initiate the input-parameters are produced randomly using a random vector.

$$R = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

Here, is the random generation and are the cost reducing parameters of transmission line.

Step 3: Fitness Function

The fitness is selected based on the objective-function.

F(t) = MIN (Cost)

Step 4: Searching the Prey

Cheetahs are motivated to search, whether it be scanning or actively looking for prey in their search region or a nearby area. At the hunting time based on the prey's state, the coverage of the area, and the condition of the cheetahs themselves, a chain of these 2 search modes may be selected by the cheetahs. Let $Y_{i,j}^{t}$ denoted as the current position of the cheetah i (i=1,2,3…n) in jth arrangement (j=1,2,3…D), where, D is denoted as the size of the optimization issue, n represents the count of cheetah's population. Based on their current position, a random search equation is supplied to update the location of every cheetah in every arrangement, and an arbitrary step is also presented. $Y_{i,j}^{t+1} = Y_{i,j}^{t} + r_{i,j}^{-1}.\ \alpha_{i,j}^{t}$

Where, the randomization parameter and step length for cheetah i in jth arrangement denotes $r_{i,j}^{-1}$ and $\alpha_{i,j}^{t}$ the next and the present locations of the cheetah i in jth arrangement denotes $Y_{i,j}^{t+1}$ and $Y_{i,j}^{t}$ Index t is denoted as the present hunting period.

Step 5: Sit-and-Wait

As a cheetah is searching, it might be able to view the prey. All the movement that Cheetah makes in this situation has the ability to alert the prey of his or her presence and run away. This worry may push the cheetah to ambush so as to get close enough to the prey (lying on the ground or hiding among the bushes). In this phase, this waiting ends by cheetah waiting for the prey to approach it from a distance.

$Y_{i,j}^{t+1} = Y_{i,j}^{t}$

Where, the updated and present locations of cheetah i in jth arrangement denotes as $Y_{i,j}^{t+1}$ , $Y_{i,j}^{t}$

Step 6: Attack Approach

Cheetahs' chase when they attack their prey rely on two major hints, speed and adaptability. When they decide to attack, cheetahs move very quickly towards the prey. When the prey realizes that it is being attacked by a cheetah it begins to flee. The cheetah has sharp eyes, runs with great speed and chases the prey in the interception path quite fast. Sometime later, the cheetah follows the position of the prey and it adjusts its direction of movement to block the path of the prey at one point.

Step 7: Termination

In this present case, this method is utilized in two scenarios; firstly, if the cheetah does not take its prey, it either changes position or goes back to its territory. (2) If the cheetah has been unable to snatch something to eat for an extended time, it may move to the area it last hunted, then the neighbouring area as well.

The termination criteria are checked to see if the optimal solution is found, so the process is ends. Otherwise, proceed to step 3.

**Calculation of Constraints:**

Minimum clearance requirements are thought to be boundary conditions to be taken into consideration. Constraints are discussed as minimum spacing between conductors and earthed objects and between individual live conductors. The optimal arrangements for overhead phase conductors of the transmission lines are obtained by using above values in the COA optimization program. To meet the insulation coordination criteria, minimum clearance values are needed between live conductors and also between phase and earthed objects. The calculations of air clearances need to be performed under various conditions, i.e. for lightning strikes, switching surges and power frequency voltage level. The notations of the above three events are as follows.

ff - for fast front (lightning phenomena) over voltages

sf - for slow front (switching surge) over voltages pf - for power frequency over voltages

**Development of Objective Function for Optimization:**
To decide the superior coordinates of conductors in unmarried or double-circuit overhead hybrid transmission traces, a multi-objective optimization feature is formulated. These characteristic ambitions to decrease two wonderful targets simultaneously, even as adhering to particular constraints, as mentioned under:

$$\min_{y,z} \{f(E(y,z), B(y,z))\}$$

Subjected to $g_m(y,z) \leq 0; m = 1,2, \ldots, M$

$y_n^{(L)} \leq y_n \leq y_n^{(U)}$ and $z_n^{(L)} \leq z_n \leq z_n^{(U)}; n = 1,2, \ldots N$

**E(y, z), B(y, z)** - the objective functions: the total effective value of the electric field strength and magnetic flux density of the overhead line, respectively
**y, z** - the vectors of decision variables (heights of the conductor above ground level and conductor distance in direction of cross arm perpendicular to the line direction, respectively)
$\boldsymbol{g_m(y,z)}$- the inequality constraints
**M** - the number of inequality constraints
$\boldsymbol{y_n^{(L)}, y_n^{(U)}, z_n^{(L)}, z_n^{(U)}}$ − lower and upper limits of decision variables
**N** - the number of conductors
**Et_dc** (vector): Magnitude of the DC electric field
**Bt_dc** (vector): Magnitude of the DC magnetic field

The research introduces minimum value constraints which researchers denote as $g_m(y,z)$ to validate design parameter satisfaction. The set of constraints includes three fundamental elements which consist of phase-to-phase distance minimum requirements, the required spacing between AC and DC conductors and ground clearance specifications. The Multi-Objective Constrained Optimization faces these constraints through the implementation of Cheetah Optimization Search Algorithm (COA) by the research study. The optimization process operates within a defined search space, which consists of decision variable (y, z), ensuring that the placement of conductors meets the required safety and efficiency standards.

**Alternative Decision Framework for Determining Optimal Phase Configuration**
A multi-objective optimization function returns multiple feasible solutions instead of a single solution that optimizes the fitness function value. The set of viable design alternatives includes each point. Design engineers must select the most appropriate solution among the options provided by the multi-objective optimization function. Two other decision-making scenarios have been developed to facilitate engineering choice because they focus on audible noise and radio interference that can result from hybrid transmission lines.
Minimize the audible noise level generated by transmission line. (Minimal audible noise scenario)

$$\min_{AN(y_p^*, y_p^*)} \{f(E(y_p, z_p), B(y_p, z_p))\}$$

Minimize the radio interference generated by transmission line. (Minimal radio interference scenario)

$$\min_{RI(y_p^*, y_p^*)} \{f(E(y_p, z_p), B(y_p, z_p))\}$$

**Modelling of Optimization Problem**
An objective function was formulated to optimize the structural design and enhance the compaction of EHVAC-HVDC hybrid transmission line towers. The Cheetah Optimization Algorithm facilitates the optimization process. Essential inequality constraints and bounds are incorporated to ensure adherence to minimum electrical clearances. The objective function crafted in this research integrates the combined impacts of electromagnetic fields and corona phenomena to refine the design of the specified hybrid transmission line. Tower compaction leads to a reduction in the Right of Way, yielding cost savings in land acquisition. The determination of the Right of Way primarily depends on electric field intensity. Guidelines from ICNIRP and Central Board of Irrigation and Power (CBIP) provide maximum permissible exposure limits for electromagnetic fields and RI/AN. These levels must be assessed at the boundary of the Right of Way, which dictates total width of hybrid line corridor. Table 3 presents the limiting values recommended by these guidelines.

**Table: 3 Key design limits for hybrid 400 kV ac/500 kV dc line [26]**

| Parameter | Limit | Comment or Rationale |
|---|---|---|
| Hearing sound during favourable weather conditions | ≤ 42 dBA | At the servitude boundary the 24-hour Ldn exceeds the night-time limit of 35 dBA specified in SANS0103 by 7 dB. |
| Audible sound during precipitation | ≤ 55 dBA | 24-hour *Ldn* at the brink of servitude. |
| The radio disturbance | ≤ 72 dB (1μV/m) at 0.5 MHz | *L50* limit at servitude boundary. |
| Field of electricity at terrestrial elevation | ≤ 20 kV/m | Taking into account space charge, permitting combustion. |
| The magnetic field at terrestrial elevation | ≤ 40 mT | Unaffected by space charge |
| Field of electricity at terrestrial level | ≤ 5 kV/m | The ICNIRP limit is applicable at the boundary of the servitude, with no restrictions enforced within the servitude itself. |
| The magnetic field at terrestrial elevation | ≤ 100 μT | The ICNIRP limit applies at the servitude boundary, with no restrictions imposed within the servitude. |

The optimization process must account for these limiting values and ensure that the results comply with the specified maximum permissible exposure criteria. Further there are limitations posed by the electrical clearances which are to be kept for safety purpose. Considerations for the boundary conditions include the bare minimum of space between each phase and the distance in air between the tower and the conductor. These clearances are calculated as formulated in Central Board of Irrigation and Power (CBIP) Transmission line manual shown in equation below [24].

$$C_v = 0.75\sqrt{f_{75} + l_k} + \frac{V}{150}$$
$$C_h = 0.62\sqrt{f_{75} + l_k} + \frac{V}{150}$$

Here,
$C_v$ = *Vertical clearance in m;*
$C_h$ = *Horizontal clearance in m;*
$f_{75}$ = *Sag value at 75 °C in m;*
$l_k$ = *Insulator string length in m;*
*V = Transmission line potential in kV;*
Sag value of the hybrid line at 75 °C is estimated to be between 8 to 12m, and the insulator string length ranges from 3.5m to 5.5m. According to the I.E Rules 1956, the minimum ground clearance is 7m for a 400 kV EHVAC system and 9m for a 500 kV HVDC system [24]. To account for environmental effects, the minimum ground clearance adopted for the EHVAC 400kV line is 9m, and for the HVDC 500kV line, it is 12m in the Indian context [24]. Figure 3 illustrates the operation of these boundary conditions. The optimization function's value relies on the conductor arrangement, which is constrained by these requirements. These constraints define the boundary conditions for the optimization process, and minimum clearances must be upheld.

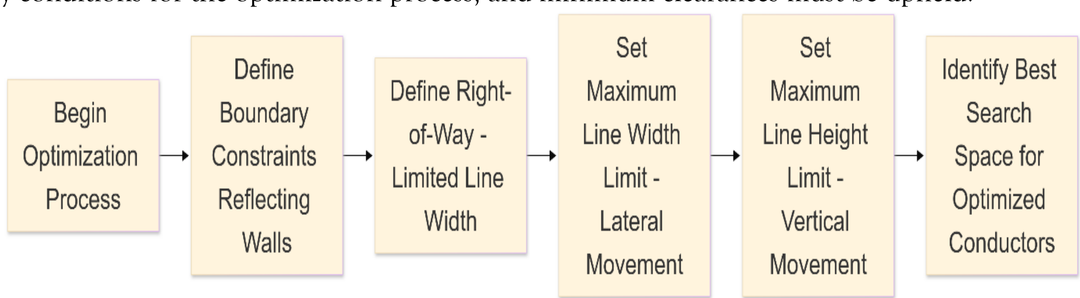



**Figure 3: Optimization boundary conditions for hybrid transmission line design**

Equation for the optimization objective function [24]:

$$f_{(E,B,An,RI)} = \left(\frac{E}{aE_m}\right)^2 + \left(\frac{B}{bB_m}\right)^2 + \left(\frac{An}{cAn_m}\right)^2 + \left(\frac{RI}{dRI_m}\right)^2$$

In this context, the calculated electric field (kV/m) and magnetic field (μT) of the hybrid line are denoted by E and B, respectively. An and RI denote the levels of audible noise and radio interference, respectively. The optimal safety thresholds for electric and magnetic fields for humans are designated as Em and Bm, respectively. Noise levels and radio interference levels are denoted by $An_m$ and $RI_m$, respectively, and their permissible limitations.
In the denominator, coefficients a, b, c, and d act as primary weighting factors for the different field effects. Given that the electric field often has the most significant influence in optimization, the first term receives the highest weight, meaning 'a' has the largest numerical value among the four factors [24].
Above objective function is to be minimized subject to

$y_n^{(L)} \le y \le y_n^{(U)}$ $\quad$ $z_n^{(L)} \le z \le z_n^{(U)}$ $\quad$ n = 1, 2, ..., N

y, z - vectors representing decision variables (conductor height above ground and spacing between conductors)
Number of conductors, N

**Hybrid Transmission Line using the proposed COA Approach**

To enhance power transfer capability and efficiency through optimal hybrid line conductor placement, the Cheetah's Optimization Search Algorithm (COA) [31] is employed. COA is a population-based meta-heuristic operating algorithm. Real-world cases of EHVAC and HVDC Hybrid Transmission Lines are examined. A specific transmission line case from Gujarat is used for the 400kV EHVAC and 500kV HVDC scenario. Recommended RoW for various voltage levels, as suggested by the Ministry of Power are considered. However, the RoW itself can be optimized to improve overall transmission line design efficiency. The optimization algorithm was applied to the previously discussed 400kV EHVAC and 500kV HVDC hybrid lines. COA was executed multiple times to ensure reliable outcomes.

**Case Studies and Optimization of different Hybrid Transmission Line Design**

This study presents a comprehensive analysis of the design and optimization of a 400 kV Extra High Voltage Alternating Current (EHVAC) and 500 kV High Voltage Direct Current (HVDC) Hybrid Transmission Line. Several essential transmission line parameters have been considered, including sub-conductor diameter, sag, splitting distance, splitting number, horizontal distance, vertical distance, DC to AC phase clearance, and AC to AC phase clearance. The parameters are important in assessing the overall efficiency, reliability, and safety of the hybrid transmission machine.

All boundary situations have been maintained according with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) tips and Central Electricity Authority (CEA) policies to make certain compliance with protection standards and electromagnetic area (EMF) publicity limits. The regulatory frameworks offer a reference to ensure that the hybrid transmission line functions inside permissible limits while optimizing overall performance.

The effects from the optimization manner were compared with the authentic values to evaluate the improvements attained. The optimized values have been verified against the initial design parameters to illustrate the efficacy of the proposed optimization framework. The comparative analysis demonstrates enhancements in line efficiency, reduced electromagnetic field exposure, minimized conductor losses, and optimized phase clearances, thereby rendering the proposed hybrid transmission line design more robust and economically viable.

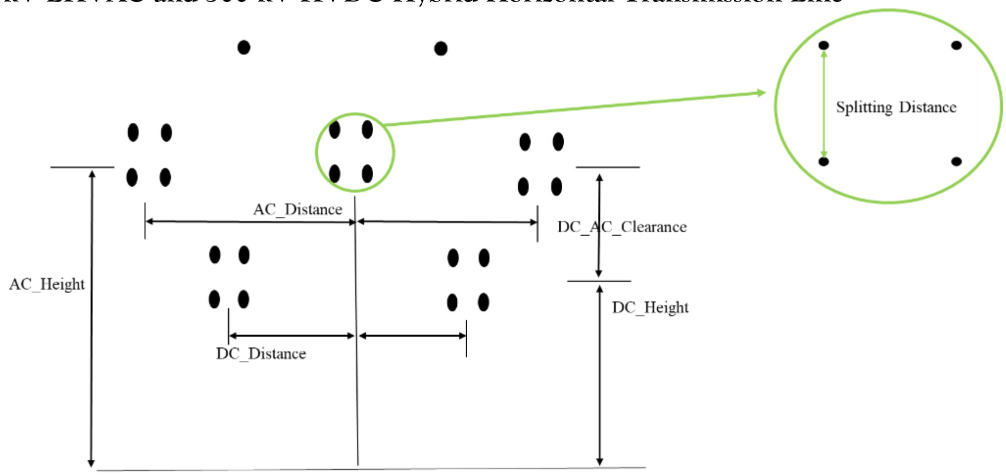
Data base for a 400 kV Extra High Voltage Alternating Current (EHVAC) and 500 kV High Voltage Direct Current (HVDC) Hybrid Transmission Line are as below:

| Sr. No. | Parameter | EHVAC | HVDC | Remarks |
|---|---|---|---|---|
| 1 | Voltage (kV) | 400 | ±500 | Delta Connection |
| 2 | Current (kA) | 2 | 4 | RMS Value |
| 3 | Power (MW) | 670 | 2000 | Power Transfer Capacity |
| 4 | Sub conductor Diameter | 40.69 | 40.69 | (Value is in mm) |
| 5 | Sag | 9-14 | 8-13 | (Value is in Meter) |

| | | | | |
|---|---|---|---|---|
| 6 | Splitting Distance | 457.2 | 457.2 | (Value is in mm) |
| 7 | Splitting number | 4 | 4 | NA |
| 8 | D Horizontal Distance | 15 - 24 | 8 - 11 | (Value is in Meter) |
| 9 | H Vertical Distance | 22 - 44.7 | 18 – 39 | (Value is in Meter) |
| 10 | DC to AC Phase Clearance | 10 | | (Value is in Meter) |
| 11 | AC to AC Phase Clearance | 5.09 – 24.68 | | (Value is in Meter) |

The table above displays the data that originates from Adel (2014). The same hybrid transmission line receives optimization treatment by applying the developed objective function. The primary purpose in each instance is to reduce electromagnetic field emissions through conductor reconfiguration methods to establish the best conductor layout for optimal right-of-way performance.

**Case of 400 kV EHVAC and 500 kV HVDC Hybrid Horizontal Transmission Line**




**Proposed Hybrid Horizontal Transmission line Model**

An optimized design for a simple horizontal hybrid transmission line requires the configuration and corresponding coordinates which the table below provides. The obtained results using this newly developed fitness function get validated through direct comparison with the findings from the original study provided by the referenced author.

| Sr. No. | Description | Original Value | Optimized Value |
|---|---|---|---|
| 1. | Elevation of R Phase above earth surface at Tower in (m) | 28.7 | 26.4 |
| 2. | Elevation of Y Phase above earth surface at Tower in (m) | 28.7 | 26.4 |
| 3. | Elevation of B Phase above earth surface at Tower in (m) | 28.7 | 26.4 |
| 4. | Elevation of DC + Phase above earth surface at Tower in (m) | 18.7 | 16.8 |
| 5. | Elevation of DC - Phase above earth surface at Tower in (m) | 18.7 | 16.8 |
| 6. | Spacing of R Phase above earth surface at Tower in (m) | 15.9 | 16.4 |
| 7. | Spacing of Y Phase above earth surface at Tower in (m) | 0 | - |
| 8. | Spacing of B Phase above earth surface at Tower in (m) | 15.9 | 16.4 |
| 9. | Spacing of DC + Phase above earth surface at Tower in (m) | 9.4 | 9.8 |
| 10. | Spacing of DC - Phase above earth surface at Tower in (m) | 9.4 | 9.8 |

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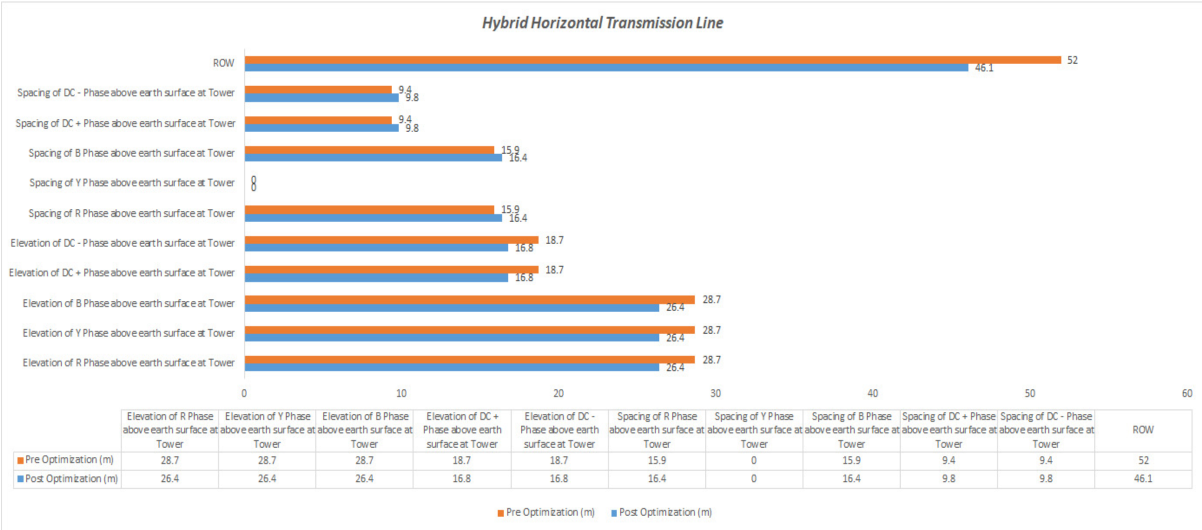
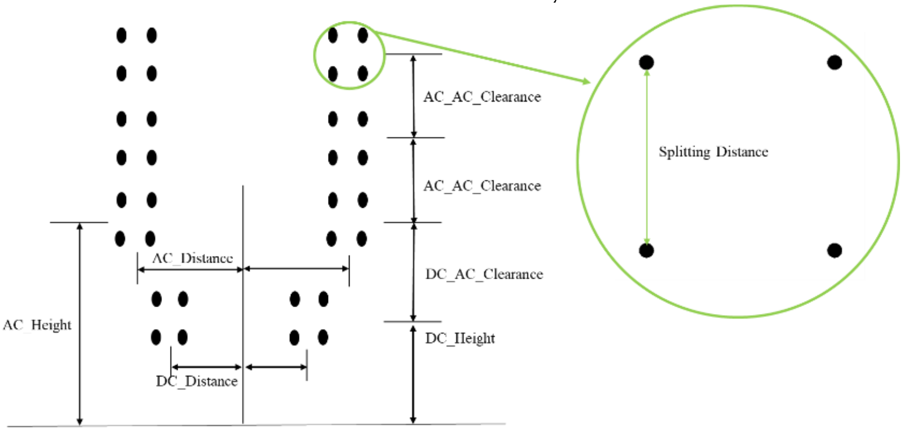



**Figure 5: Comparison of pre optimization and post optimization values for hybrid horizontal configuration**

| Sr. No. | Parameters | Original Value | Optimized Value | Remarks |
|---|---|---|---|---|
| **1.** | Electric field | 4.98 | 4.93 | kV/m |
| **2.** | Magnetic field | 34.6 | 34.6 | uT |
| **3.** | Audible Noise | 52.62 | 52.33 | Rain |
| | | 49.12 | 47.12 | Fair |
| **4.** | Radio Interference | 60.47 | 56.98 | Rain |
| | | 55.40 | 55.60 | Fair |
| **5.** | Right of Way (m) | 52 | 46.1 | Meter |

**Case of 400 kV EHVAC and 500 kV HVDC Double Circuit Hybrid Transmission Line**




| Sr. No. | Description | Original Value | Optimized Value |
|---|---|---|---|
| 1. | Elevation of R Phase above earth surface at Tower in (m) | 36.79 | 31.8 |
| 2. | Elevation of Y Phase above earth surface at Tower in (m) | 42.28 | 37.4 |

| | | | |
|---|---|---|---|
| 3. | Elevation of B Phase above earth surface at Tower in (m) | 47.77 | 42.5 |
| 4. | Elevation of DC + Phase above earth surface at Tower in (m) | 26.79 | 23.8 |
| 5. | Elevation of DC - Phase above earth surface at Tower in (m) | 26.79 | 23.8 |
| 6. | Spacing of R Phase above earth surface at Tower in (m) | **17.4** | **18.4** |
| 7. | Spacing of Y Phase above earth surface at Tower in (m) | 17.4 | 18.4 |
| 8. | Spacing of B Phase above earth surface at Tower in (m) | 17.4 | 18.4 |
| 9. | Spacing of DC + Phase above earth surface at Tower in (m) | 10.4 | 10.9 |
| 10. | Spacing of DC - Phase above earth surface at Tower in (m) | 10.4 | 10.9 |

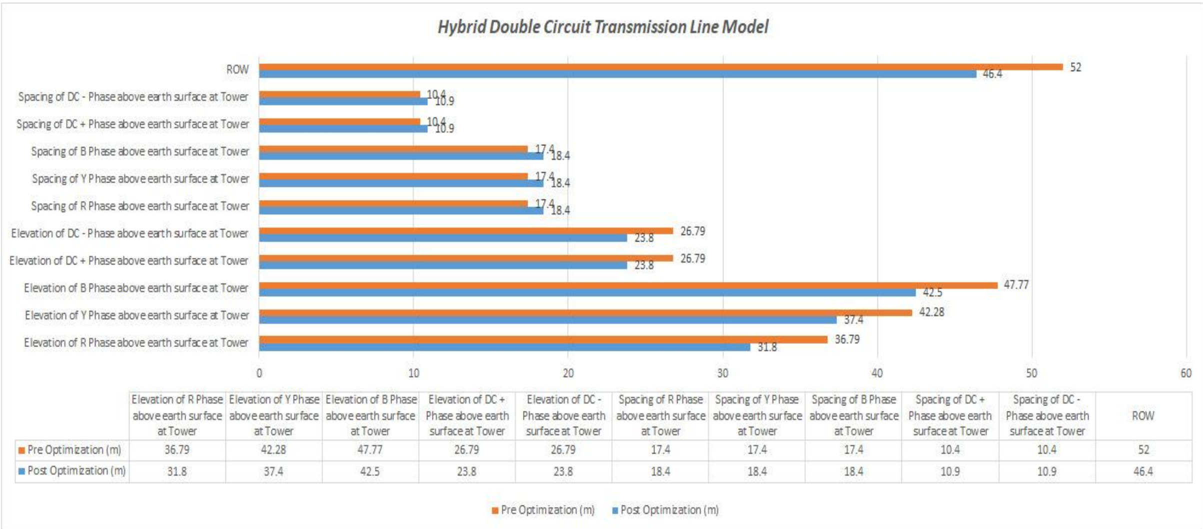



**Figure 5: Comparison of pre optimization and post optimization values for double circuit hybrid configuration**

| Sr. No. | Parameters | Original Value | Optimized Value | Remarks |
|---|---|---|---|---|
| 1. | Electric field | 5.2 | 4.99 | kV/m |
| 2. | Magnetic field | 73 | 67 | uT |
| 3. | Audible Noise | 52.9 | 52.62 | Rain |
| | | 49.9 | 49.12 | Fair |
| 4. | Radio Interference | 55.47 | 50.33 | Rain |
| | | 55.40 | 49.18 | Fair |
| 5. | Right of Way (m) | 52 | 46.10 | Meter |

Based at the outcomes from all of the cases above, it can be concluded that for both 400 kV EHVAC and 500 kV HVDC systems—whether for single-circuit or double-circuit hybrid transmission traces with any configuration of conductors within the circuits a most useful solution may be performed. Further, considering the consequences within the case of the double-circuit hybrid transmission line, it's miles clear that the fitness function developed here for multi-goal optimization is able to give first-class results for finding the most beneficial conductor arrangements to limit electromagnetic discipline results and minimize right-of-way. Also, the above cases confirm that the proposed hybrid transmission line configurations alongside the optimization toolset satisfactorily provide dependable initial stage consequences to give the layout engineer a high-quality perception and kick-start for the layout of hybrid transmission traces starting from the EHV stage to the UHV stage without compromising the safety and minimal subject clearance requirements. The research findings can be observed through two important achievements. The study develops a suitable hybrid transmission line model which fits both standard single and double circuit hybrid transmission lines alongside different conductor setups. This model delivers satisfactory simulations of electromagnetic field effects together with noisy acoustic frequencies and radio frequency disturbances produced by the transmission line system. While doing so fitness feature looks after preserving the sector consequences nicely below most permissible exposure values precise through countrywide and worldwide standards.

## CONCLUSION:

A novel multi-objective function is developed to optimize the different hybrid transmission line configurations. These minimum clearance values will be decided according to the guidelines given by national authorities like CBIP and CEA and international agencies like IEC—67000-1 and IEC 67000 – 2. ICNIRP guidelines and CBIP guidelines are considered to find criteria for maximum permissible exposures to electric and magnetic fields. The optimization algorithm was deployed to study different hybrid transmission lines for determining their best structural design. The identification of optimal conductor arrangements and proper conductor coordinates happens to minimize total electric and magnetic field effects throughout the transmission corridor. The evaluation shows that major compaction of tower structures accompanied by cost reductions becomes feasible. The structural optimization paired with reduced electromagnetic effects enables reduction of right-of-way requirements when building power lines along the transmission corridor.

The COA method is realized in the MATLAB/Simulink platform as well as assessed its performance. As a boundary condition / constraint condition for Hybrid Transmission Line Electric field limit is 5 kV/m, Magnetic Field limit is 100 uT, Power Transfer Capability limit 1400 MW to 2000 MW (HVDC) and 400 to 670 MW (EHVAC), Sub conductor diameter 28 to 38 mm, Sag 10-to-15-meter, Height of Conductor 20 to 55 m (HVDC) and Conductor - Conductor clearance 4 to 14 meter and RoW as 45 m to 53 meters.

**Optimized value of proposed COA for double circuit hybrid transmission line configuration**

| Types of Line | Conductor Diameter (mm) | Horizontal Distance (m) | Vertical Distance (m) | Power Transfer (MW) | Efficiency (%) | Total Cost (Rs.) | Remarks |
|---|---|---|---|---|---|---|---|
| Hybrid Line | 33 | 8.5 | 31.8 | 670 | 80.5 | 30 % | EHVAC |
| | 37 | 9.2 | 23.8 | 2000 | 95 | | HVDC |

This research examined the effectiveness of the algorithm toward Hybrid Transmission Line Problem solutions and performed necessary feasibility studies. The proposed method shows evidence of achieving improved quality solutions and demonstrates better convergence qualities and increased robustness than traditional optimization algorithms do. Future studies should concentrate on creating a cost model while implementing maximum constraints on the expenses of AC to DC converter stations. The orientation of tower structures requires integration as an additional aspect into the developed multi-objective optimization algorithm.

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