Multi Objective Dynamic Economic Dispatch with Renewable Energy and HVDC Transmission Lines

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Abstract: **HVDC systems have recently found increasing importance in integration of Renewable energy (RE) into the grid for they provide long distance bulk power transmission by overhead lines with various economic advantages. The proposed 1045 km, 500kV HVDC Ethiopia – Kenya Bipole will provide transmission of Wind power from the Lake Turkana Wind Power Project (LTWWP) to Juja Substation in Nairobi, Kenya. In this paper, multi objective dynamic economic dispatch (MODED) with RE and HVDC transmission lines is proposed. All the possible AC and DC constraints are also formulated and considered. Probalistic load flow (PLF) is used to determine the HVDC, RE and other system parameters while the uncertainties and variability of the renewable sources are modelled using scenario based method (SBM).The problem is then solved using Improved Genetic Algorithm(IGA). For MODED with RE, HVDC lines have a better ability to control power flow, decrease transmission line losses and increase the capability to maintain voltage stability. There has to a trade-off between the environmental benefits and slight increase in optimal cost in using HVDC grids.**

Key Words: HVDC, Probalistic Load Flow (PLF), Multi Objective Dynamic Economic Dispatch (MODED), Renewable Energy (RE)

I: INTRODUCTION

Several works have considered multi objective dynamic economic dispatch (MODED) with renewable energy (RE). Methods used in thermal &wind objective cases include Simulated Annealing (SA) and Direct Search Method (DSM)-(SA-DSM) [1] and Variable Time Resolution (VTR) and Scheduling Horizon (SH)-(VTR-SH) [2]. Thermal, wind & solar objectives have been considered in [3] using Model Predictive Control (MPC). Two works have considered thermal, wind, solar & emissions, first using Non Linear Constrained Method (NLCM)[4] and then applying Weighted Aggregation (WA) and PSO-(WA-PSO)[5].In all these works, however ,only HVAC transmission lines are used.

Two recent works have considered economic dispatch(ED) with HVDC grids. In [14], there is an introduction of HVDC grids, their corresponding technical and economic merits. The proposed modes of analysis include HVDC model set up, DC lines converters and losses, integrated AC/DC ED, uncertainty models and security constraints. Simulation is carried out on CIGRE B4-58 system. In this work however, these concepts have not been formulated. In [13], Improved Genetic Algorithm (IGA) was compared with optimal power flow (OPF) in the solution of formulated ED with HVDC lines. HVDC lines led to reduced real and reactive losses. Further, there was 50% increase on the optimal cost due to the increased cost of the converters and inverters. However, the HVDC lines led to reduced convergence time of the IGA and improved voltage stability of the system. In this work, the presence of RE has not been considered. This paper therefore investigates the need for HVDC transmission lines in MODED with RE.

Paper Organization: The rest of the paper is organized as follows; section II gives a brief outline of the Kenya-Ethiopia Bipolar Line, section III is the problem formulation, section IV provides the proposed methodology, section V is results and analysis, section VI is the proposed multi terminal DC (MTDC) East Africa Interconnection ,then, section VII is the paper conclusion.

II: THE KENYA-ETHIOPIA BIPOLAR LINE

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 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 which are closely associated with the HVDC-ED results, these 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].

III:PROBLEM FORMULATION

A: Thermal Cost Function: The general form of single objective dynamic economic dispatch (SODED) with more accurate cubic cost function can be formulated as

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

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Where $a_{0,i,}a_{j,i}, e_i$ and f_i are the cost coefficients of the i^{th} unit, $P_i^{min}$is the lower generation bound for the i^{th}unit and $r_i$is the error associated with the ith equation.

B: Renewable Cost Functions: The operational cost objective function for wind power generation is formulated in [10] as

$$F(w_{ij}) = F_{wi}(w_{ij}) + F_{p,wi}(w_{ij,av} - w_{ij}) + F_{r,wi}(w_{ij} - w_{ij,av}) \qquad (2)$$

where w_{ij} is the scheduled output of the i^{th} wind generator in the j^{th} hour, $F_{wi}(w_{ij})$ is the weighted cost function representing the cost based on wind speed profile, $F_{p,wi}(w_{ij,av} - w_{ij})$ is the penalty cost for not using all the available wind power and $F_{r,wi}(w_{ij} - w_{ij,av})$ is the penalty reserve requirement cost which is due to the fact that that actual or available power is less than the scheduled wind power. Similarly, the operational cost objective function for the PV power generation plant is formulated as [10]

$$F(PV_{ij}) = F(PV_{ij}) + F_{p,PVi}(PV_{ij,av} - PV_{ij}) + F_{r,PVi}(PV_{ij} - PV_{ij,av}) \qquad (3)$$

$F_{PVi}(PV_{ij})$ is the weighted cost function representing cost based on solar irradiance. The other two are the respective penalty costs.

It should be noted that wind is available throughout the day at different locations with varying speed while sunlight is available only for a particular duration of the day at varying intensity. The main aim of introducing solar cost function is to extract maximum amount of power from solar reactor during its available period (T_a). Some part of solar power generated during this period is stored using some available storage devices called Renewable Energy Reserve(RER). This stored power is delivered during unavailable period (T_u) of sunlight. The power extracted from the renewable source varies and can be considered as a variable (intermittent) load. Therefore this power, $(PV_{ij,av} + w_{ij,av})$, is deducted from the total demand (P_D^t) and also the stored power (P_R) is added to it (duringT_a) or subtracted from it (during T_u)to obtain the actual demand(P_D^a)which is distributed among the available generating units. The dispatched amount of renewable power is limited to some part (x) of the total actual demand. The stored power is the difference of the total extracted and dispatched amount of renewable power during Ta. During T_u it must not exceed some part (y) of the total stored renewable power of T_a period. Moreover, the sum of total power delivered from the storage devices during T_u must not exceed the total power stored during T_a [11]

C: Transmission Loss Cost Function: The cost of transmission line losses between plants are accounted with the actual fuel cost function by using a price factor g_i .This factor is defined as the ratio between the fuel cost at its maximum power output to the maximum power output. Thus, the cost function for the losses at a particular time becomes

$$\mathrm{F}(P_{L,AC}) = \sum_{i=1}^{n} g_i\left(\alpha_{3,i}\, P_{t,i}^3 + \alpha_{2,i}\, P_{t,i}^2 + \alpha_{1,i} P_{t,i} + \alpha_{0,i} P_{t,i}\right) \qquad (4)$$

It is assumed that the losses due to the REs are negligible since they are located near the load center. Thus the overall cost for the losses is given by

$$\mathrm{F}(P_{L,i}) = W\mathrm{F}(P_{L,AC}) + (1-W)\mathrm{F}(P_{L,DC}) \quad (5a)$$

Integration of HVDC lead to a reduction in real losses (11.85%) and reactive losses (8.09%)[13].Thus ,by average,the total losses cost can be given by

$$\mathrm{F}(P_{L,i}) = [0.1W + 0.9]\mathrm{F}(P_{L,AC}) \quad (5b)$$

Where W is a weighting factor defining the loses in the AC and DC systems. This number depends on the number of HVDC and HVAC lines in the system

D: Emissions Function: The three main emissions that are considered include NO_X , SO_2 and CO_2 for the power plants in the MODED system. The emissions cubic function is given by

$$\mathrm{E}(P_{i,3}) = \beta_{3,i} P_{t,i}^3 + \beta_{2,i} P_{t,i}^2 + \beta_{1,i} P_{t,i}^1 + \beta_{0,i} + \zeta_{3,i} \exp(\lambda_{3,i}\ P_i) + \zeta_{2,i} \qquad (6)$$

Using equations (1), (2), (3), (5b) and (6), MODED Formulation: MODED problem with RE is then summarized as

$$\min f = \min[W_1 F + W_2\, E] \qquad (7)$$

Where

$$F = \sum_{i=1}^{n} F(P_{ij}) + \sum_{i=1}^{W} F(w_{ij}) + \sum_{i=1}^{S} F(PV_{ij}) + \mathrm{F}(P_{L,i}) \text{ and}$$

$$E = \sum_{i=1}^{n,W,S} E(P_{ij}, PV_{ij}, w_{ij})$$

where $W_1, and\ W_2$ are non-negative weights used to make tradeoff between emission security and total fuel cost considering the three fuels such that W_1+W_2 =1. W_1 is the algebraic sum of the individual weight of the four objectives, n, W and S are the number of thermal wind farm and PV power plants.

The problem is solved subject to the combined, renewable energy ,HVAC and HVDC constraints which are listed here under:

i) Combined Constraints (CC)

$$\sum_{i=1}^{n} P_{ij} + \sum_{i=1}^{W} Pw_{ij} + \sum_{i=1}^{S} PV_{ij} = P_{Dj}^a + P_{loss\ j} \quad (8a)$$

$$P_r\left[\sum_{i}^{n} P_{im} + \Omega(w_{ij} + PV_{ij})\right] \le P_{Dj}^a + P_{loss\ j} \le P_a \qquad (8b)$$

$$P_D^a = P_D^t - (PV_{ij,av} + w_{ij,av}) \pm P_R \qquad (8c)$$

$$(PV_{ij} + w_{ij})_d \le x P_D^a \qquad (19)$$

$$P_R \le (PV_{ij,av} + w_{ij,av})_g - (PV_{ij} + w_{ij})_d \qquad (8d)$$

$$P_R \le y \sum_{T_a} (PV_{ij,av} + w_{ij,av})_g - (PV_{ij} + w_{ij})_d \qquad (8f)$$

$$\sum_{T_u} P_R \le \sum_{T_a} P_R \qquad (8g)$$

ii) Renewable Energy Constraints (REC)

$$0 \leq w_i \leq w_{ri} \qquad (9a)$$

$$0 \leq PV_i \leq PV_{K_t\, max} \qquad (9b)$$

iii) HVAC Constraints (HAC)

$$P_i^{min} \leq P_i \leq P_i^{max} \qquad (10a)$$

$$P_{ij} - P_{ij-1} \leq UR_i \qquad (10b)$$

$$P_{ij-1} - P_{ij} \leq DR_i \qquad (10c)$$

$$-P_l^{max} \leq P_{lj} \leq P_l^{max} \; l = 1,2,3 \ldots\ldots L \quad (10d)$$

$$P_i \leq P^{PZ,LOW} \qquad (10d)$$

$$P_i \geq P^{PZ,HIGH} \qquad (10e)$$

iv) HVDC Constraints (HDC)

- HVDC Converter Tap Ratio Constraint (MCTRC)

$$T_{min} \leq T \leq T_{max} \qquad (11a)$$

- HVDC Converter Ignition Angle Constraint (MCIAC):Facilitates fast and reliable control of power flows

$$\alpha_{min} \leq \alpha \leq \alpha_{max} \qquad (11b)$$

- HVDC Converter extinction Angle Constraint (MCEAC):Facilitates rapid control to increase transient stability limit

$$\gamma_{min} \leq \gamma \leq \gamma_{max} \qquad (11c)$$

- HVDC Current Constraint (HCC)

$$I_{dc,min} \leq I_{dc} \leq I_{dc,max} \qquad (11d)$$

- HVDC Voltage Constraint (HVC)

$$V_{dc,min} \leq V_{dc} \leq V_{dc,max} \qquad (11e)$$

IV:PROPOSED METHODOLOGY

In this section, we consider the probalistic load flow(PLF) for the MAMODED with RES, uncertainty and variability modelling of the RE sources using Scenario-based method (SBM) and a summary of the solution process using improved genetic algorithm (IGA).

A: Probabilistic Load Flow (PLF)

The three main objectives of load flow analysis are to determine the static operating state of the power system for given loads, voltage magnitude and angle at all the buses and finally the line flows and system losses. Load flow methods are classified into two deterministic and probabilistic methods. In this paper, probalistic load flow (PLF) is applied since it utilizes different mathematical approaches such as probabilistic approach, fuzzy sets, interval analysis etc. for taking into account uncertainty in RES.Further, it requires inputs with probability density function (PDF) or cumulative density function (CDF) which are the distribution functions of wind speed and solar radiation intensity [12]

The PDF involves buses such as PQ (negative load), PV (voltage controlled), PX and RX. Numerical and Analytical methods are applied in solving the PLF. The analytical methods analyses a system and its inputs using complex mathematical expressions .The load flow equations are linearized hence inaccurate due to the different approximations. On the other hand, numerical methods involve performing DLF a large number of times with inputs of different combinations of nodal power values. Exact non-linear form of load flow equations can be used using Monte Carlo Simulations. Thus, in this paper, numerical methods will be used although it is time consuming [12].

AC PLF Model for Renewable Energy System (RES)

The PLF model is given by

$$w = f(x), \Delta x = J_0^{-1}\Delta w = S_0 \Delta w \quad (12a)$$

$$z = g(x), \Delta z = G_0 J_0^{-1}\Delta w = T_0 \Delta w \quad (12b)$$

Step 1: Read the power system , wind DFIG and Solar PV data

Step 2: Run the normal deterministic load flow (DLF) using newton raphson (NR) method, so that the expected values of nodal voltages, line flows, S_0 and T_0 are obtained.

Step 3: Compute the cumulants of the generation and the loading according to their probability density function (PDF)

Step 4: Compute the cumulants of the generated active power, absorbed reactive power, power injections and the state variables (Δx and Δz)

Step 5: Obtain the PDF and CDF of Δx and Δz

B: Scenario-Based Method (SBM)

For a general multivariate function, say, $y = F(X)$ where X is a vector containing the uncertain input values, the SBM uncertainty modelling is a method for finding the expected value of y. A set of scenarios, $\Omega_s$is generated for describing the probable values of X such that [8];

$$y = \sum_{s\epsilon\Omega_s} \pi_s F(X_s) \qquad (13)$$

where π_s is the probability of state s.

Uncertainties and variability in RE power generation and load profile of the system, emerge into a probabilistic MODED which is formulated in this paper. The total cost of energy is given by

$$C_T = \sum_{S,t} \pi_s PP_s(t)\lambda_s(t) + \sum_{i,t} C_i\left(P_i(t)\right) \qquad (14)$$

where C_T is the total cost paid , π_s is the probability of scenario s, $PP_s(t)$ is the purchased power from reserve pool in time t ,scenario s and $\lambda_s(t)$ is the price of energy purchased from the power reserve in time t ,scenario s($/MWh) and $C_i(P_i(t))$ is the production cost of the i^{th} thermal unit in time t.The objective function of a rational cost that is to be maximized is defined by

$$F = \sum_{S,t} \pi_s P_{D,s}(t)\lambda_c(t) - C_T \qquad (15)$$

where $\lambda_c(t)$the price of energy in time t, and $P_{D,s}(t)$ is the load demand at time t and scenario s .

C: The Solution Process

Step 1: Get the prediction data for the RE power, load and all the other known conditions using PLF

Step 2: Set the range of the RE power fluctuations and the risk constant of the load shedding

Step 3: Build the MODED model with RE

Step 4: Invoke the power system stability and security checks

Step 5: Solve the problem using improved genetic algorithm (IGA)

V: RESULTS AND ANALYSIS

A: RE Integration: Transmits large amounts of power over long distance (500-700km) without the need for reactive compensation. The HVDC lines helps in integration large amounts of variable (RE) generation. 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).Further, 1045 km, 500kV HVDC Ethiopia – Kenya Bipole will provide transmission of Wind power LTWWP to Juja Substation in Nairobi, Kenya. The parameters of such links are as shown in Tables 1.0 and 2.0.

TABLE 1.0: HVDC LINK PARAMETERS

	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 2.0: HVDC PLF RESULTS

	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	

Three cases are considered, Case1: MODED with RE and HVDC/HVAC Lines, Case 2: MODED with RE and HVAC lines and Case 3: MODED with HVDC.

B: Economic Merits: HVDC lines enable long distance transmission with lower costs and losses. There are no high capacitance effects hence no reactive losses. There is more power per conductor hence no skin effect. Further, there is less corona effect, reduced conductor insulation, lighter and cheaper towers and reduced Right-of-Way (RoW) [13]. From Figure 1.0 it can be seen that for case 1, the power losses are significantly lower than in Case 2. From Table 3.0 the cost is highest in case 3 due to the increased cost of converters and inverter. The cost can be even significantly higher since the losses presented in this work are estimates (only network losses). However in case 2 ,the cost is significantly reduced .

Figure 1.0: Power Loss in MODED with RE Vs Bus Position

TABLE 3.0: COST COMPARISONS

	Case 1	Case 2	Case 3
Total Power Transmitted (MW)	605.71	605.82	569.31
P_{LOSS} (MW)	40.712	40.82	4.307
Total fuel cost($)	10,088	6029.56	11,379.34
Convergence time(Sec)	1.9250	2.04	2.01

C: Environmental: HVDC lines require one-third fewer power conductors (wires) and insulators to transport energy than AC lines. This results in a narrower right-of-way and comparatively smaller footprint, minimizing effects on existing land use and lessening environmental impacts. Further, the lines produce less corona and cause less radio and television interference .Figure 2.0 shows the percentage change in cost and emissions for a given load curve. The ranges of the times are $0 < T_u 7$, $7 < T_a <18$, and $18 < T_u <24$. Further the use of RES reduce the emissions further to some extent. From the figure, it is clear that 40% of the fuel cost is saved during T_u in case 1 while the saving is less than 20% case 2. In practical sense ,case 3 does not exist .It should be noted that $C_{case\ 1} < C_{case\ 2} < C_{case\ 3}$ and $E_{case\ 1} < E_{case\ 2} < E_{case\ 3}$.Further the changes in emissions are very small and sometimes negative as compared to the changes in the optimal cost[8].Thus in using the HVDC technology ,there must be a tradeoff between the environmental benefits and the slight increase in cost.

D: Stability: The voltage profiles in case 1 and case 2 are as shown in figure 3.0.The effects of HVDC on power transfer depends on the difference of the phase angles between the voltages at the two ends. For a given power level, this angle increases with the length of the line. The maximum power transfer is limited by the considerations of the steady state and transient stability. The need to maintain stability imposes a serious technical limit to the distance over which power can be transmitted on a simple HVAC line. It becomes more difficult to maintain stability as the length and, therefore, the reactance of the line increases. Reactive power is to be injected at regular intervals to limit the reactive voltage drop which is the main cause of instability.

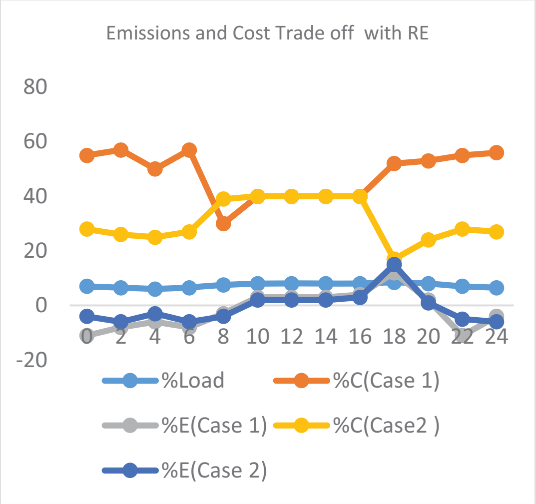

Figure 2.0: Emissions and Cost Trade off in MODED with RE Vs Time

There are no stability problems with HVDC transmission lines, therefore, there is no longer a length limitation. Thus power transfer capability of HVDC lines is unaffected by the distance of transmission. Power flow can be controlled rapidly and accurately under steady state and transient conditions. An earth return can be used in HVDC transmission. In the event of any fault on any pole in an HVDC bipolar line, the other pole with earth return acts as an independent circuit and continues to supply power. Thus there is flexibility of operation. Further due to the absence of the frequency factor with HVDC bipolar link, there is no skin effect, thus, complete cross-section of the conductor can be effectively used and more can be transmitted on the same size of the conductor with frequency stability guaranteed. The stability studies can form a promising area of further research.

Figure 3.0: Voltage profile in MODED with RE Vs Bus Position

VI: MTDC EAST AFRICA INTERCONNECTION

HVDC connection between Kenya and Ethiopia can be utilized to achieve Asynchronous coupling between the two countries. The same technology can be extended to cover the rest of East Africa Region(Uganda Tanzania and Somalia) using the multi terminal HVDC(MTDC) tie lines proposed in Table 4.0. This will result in a five-area multi area MODED (MAMODED) which can be further investigated.

TABLE 4.0: MTDC TIE LINE FLOW LIMITS

MTDC Tie Lines	Power(MW)
T_{1-3}	2350
T_{1-4}	1300
T_{1-5}	2350
T_{2-3}	3300
T_{3-5}	2350
T_{2-4}	2350

MTDC has more than two converter stations and interconnecting HVDC transmission lines. Radial MTDC is the HVDC system of choice for the multi area asynchronous tie lines proposed in this paper because of the following reasons[8]: (i)It is more flexible and economical (iii)Frequency oscillations in the areas can be damped quickly(iii) There is inherent overload capability. Hence transient stability of the interconnected system is increased without an increase in installed capacity. Thus, the overall stability of the multi area system is improved. (iv)Heavily loaded AC area networks can be reinforced by using MTDC systems. Two important constraints must be defined for the MTDC interconnections between the various countries; MTCL and MTLFC. MTDC Transmission Capacity Limits (MTCL) is defined as the transfer including both generation and reserve from area m to k should not exceed the MTDC tie line transfer capacities for security considerations .This can be expressed as

$$T_{mk,min} \leq T_{mk} + R_{mk} \leq T_{mk,max} \tag{16}$$

Where $T_{mk,min}$ and $T_{mk,max}$ represents the MTDC tie line transmission capability

On the other hand, MTDC Tie Line Flow Constraint (MTLFC) is also defined as

$$|P_t| \leq P_{t,max} \; t = 1,2,3 \ldots \ldots . . N_t \tag{17}$$

where N_t the number of is tie lines and P_t is the active power flow in the tie line t. In this case the areas being interconnected are the countries in the East African Region. It is worth to note although there are no stability issues within the MTDC network, when it is part of interconnected HVAC systems, the overall stability is still governed by the HVAC's transient and voltage stability features. This is an area proposed for further research and development.

VII: RECOMMENDATIONS FOR FURTHER WORK

Further, to make the findings of this work feasible the following challenges on HVDC technology and assumptions made need to be further addressed for they have economic implications:

- *Protection*: circuit breaking is very challenging in HVDC circuits and therefore the cost of HVDC circuit breakers is very high.
- *Transformers*: HVDC systems have no step up or step down transformers to facilitate change in voltage levels.
- *Converter Stations Cost*: The cost of the terminal stations is very high. Further, both AC and DC harmonics are generated hence

the need to have both types of filters .This increases the cost of the converters further.

- *System Cooling*: The substations have additional losses due to switching in converters and transformers. An effective cooling system is thus required to dissipate the heat.
- *Overall efficiency:* The losses presented in this work are just estimates based on network losses and this can be verified with the existing HVDC installation exemplars[12-14] .Other losses like switching losses, need to be considered also. Thus a detailed modelling of the overall system losses is paramount.
- *Control: The* control system in a HVDC link is quite complex and thus musty be investigated further.

VIII: CONCLUSION

In this paper MODED with RE and HVDC Lines has been presented. Probabilistic load flow (PLF) and scenario based method (SBM) has been applied to determine the system parameters and to handle the uncertainties respectively. Improved Genetic Algorithm (IGA) has been incorporated in the solution process. The simulated results illustrate the technical, economic and environmental merits of using HVDC lines. Further use of multi terminal HVDC (MTDC) enhance the security and stability of the two interconnected systems holding the transient and voltage stability features of the HVAC systems (areas) constant.

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