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Stability Enhancement of HVDC Line by Firefly Controlled Pi

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Abstract: In the developing technology of power system there desired power control at every point and it is obtained by power controllers like HVDC. A large class of researchers have used VSC controlled HVDC system for transient minimisation. They have used active power and voltage controlled loop using PI controller and set the values of gain parameters in PI by hit & trial method which requires setting of gain parameters again. In our work it will be the main area of research. The main objective of this paper is to improve power transmission capacity and power quality of HVDC transmission. To avoid the settling of PI gain parameters for converter in HVDC which is computational complex, we used teacher learner based optimisation algorithm (TLBO), which on the basis of deflection of DC link voltage to reference, optimise the PI gain parameters.

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I. INTRODUCTION

I N THE future power system, the increasing number of high-voltage dc (HVDC) transmission links, imposes the serious challenges on power system control and stability analysis. While some of HVDC systems offer better controllability and improvement of global power-system stability, there is also an increased risk for local in stabilities which can either start as parasitic small signal oscillations [1], [2], or concurrent commutation failure of converters consequently impair voltage quality or cause high over-voltage at the converter ac buses [3]. To analyze the nature and causes of these instabilities, appropriate analytical models of power systems and HVDC links are required. The electro-magnetic transient programs (EMTPs), as time-domain simulation tools, demonstrate instabilities; however, they do not provide the analytical insight (e.g., information about participants in instability or stability margins) needed for optimal system design [4]. In addition, these programs have practical simulation restrictions on the extent of the ac system [5]. The conventional transient stability programs (TSPs), which use phasor modelling techniques [6], do not have these aforementioned problems, but they cannot directly represent the faster transients characterizing the HVDC systems [6]. Some authors have proposed considering EMTP based models of HVDC links into TSPs [5]–[7]; in this case, the problem of analytical investigation of instabilities still exists. To deal with these issues, authors have proposed analytical models (eigen value-based and/or frequency-domain models) of LCC-HVDC systems [2], [8]–[12]. These models are usually used in local studies, where a small portion of power system including HVDC converter is modelled in detail and the rest of the power system is replaced by an equivalent simple circuit. However, when the number of HVDC converters (and/or other power-electronic devices) is increased, the high-frequency interaction between different devices will be so complicated [13] that local analysis may not result in a reliable conclusion. Moreover, it has been declared in [14] that the HVDC controller design might suffer from lack of an accurate power system model if only the dynamics of a small portion of it is regarded. On the one hand, considering dynamics of all power components and ac system results in a huge number of state variables, of which most of are inessential. On the other hand, all of the electrical network dynamics cannot be neglected while analyzing the interactions among HVDC converters [2], [14]–[16] (otherwise, the TSPs could have been used for the same purpose). In [14], a hybrid model of power system has been proposed to overcome this problem; in fact, the areas of power system which consist of HVDC converters are modelled including ac network dynamics, and the remaining parts are modeled using the power frequency admittance matrix. Although this model reflects the nature of oscillations in power systems, but still it is not the best tool when the proportional gain of a controller causes instability. Also, the small-signal stability cannot be analyzed in the frequency domain to obtain gain and phase margins of stability, which are crucial in controller design. Moreover, in [14], the voltage-source converter-based HVDC (VSC-HVDC), which is more promising device in future power systems, has not been considered.

In this paper we have simulated HVDC line controller and stabilise the oscillations in case of DC fault using firefly tuned PI controller. Firefly is a bio inspired algorithm which was developed in 2013 and used in various applications. But as per our knowledge it is not used in controlling and stabilising the oscillations in HVDC transmission line.

II. METHDOLOGY

In our work we have tuned the PI controller parameters to minimise the oscillations in HVDC line during fault disturbance. The PI controller takes the difference between desired DC current and observed DC current of the converter side as input and control the deviation and gives the duty cycle to IGBT gate terminal of converter. To tune the gain parameters of PI we used a bio inspired Firefly algorithm which is based on the movement of fireflies and was latest introduced by Xin-She Yang in 2013. The deviation between reference DC current and observed DC current constitutes the objective function of this optimisation algorithm. A controlling block diagram is shown in figure 2 which is designed in MATLAB.

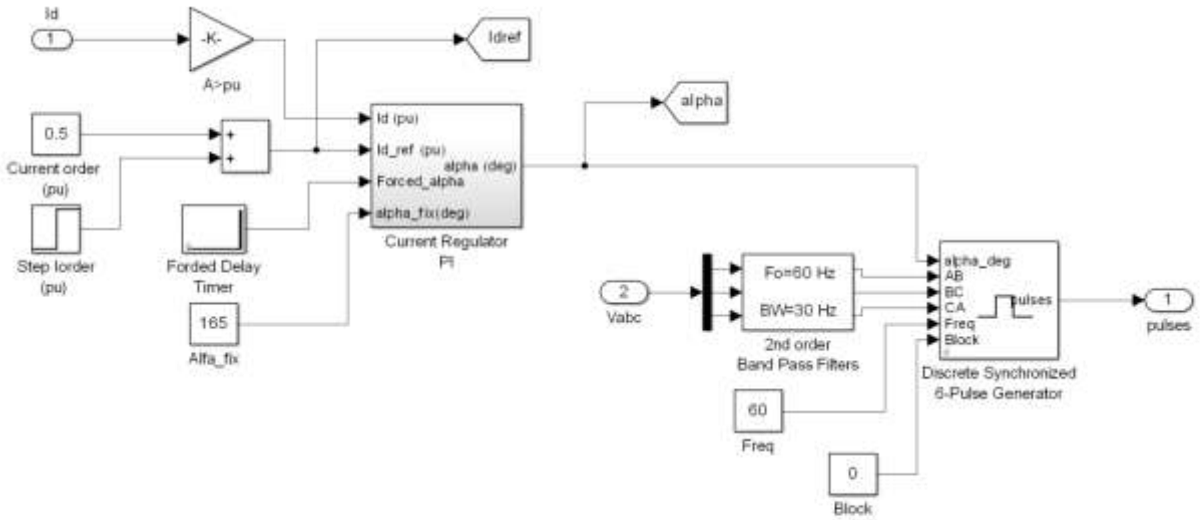

Figure 2: Block diagram of controller

To optimise the PI gain parameters, firefly algorithm (FA) set the values of proportional controller and integral controller to optimum set. The mean of error between reference DC and observed DC current is target objective function which is represented in equation 1.

$$obj\ fun = mean(I_{DC_{ref}} - I_{DC_{observed}}) \quad ...... (1)$$

There are some considerations in FA:

•Fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex.

•The attractiveness is proportional to the brightness, and they both decrease as their distance increases. Thus for any two flashing fireflies, the less brighter one will move towards the brighter one. If there is no brighter one than a particular firefly, it will move randomly.

• The brightness of a firefly is determined by the landscape of the objective function.

The positions of fireflies which are the values of PI gain parameters are randomly initialised and fed into a subroutine developed in MATLAB to calculate the mean of error after simulating the simulink model developed for HVDC line using controller. Once this is done for all positions of fireflies which are 3 in our case, the sorting is done to get the minimum error position and this position is further updated by formulation represented in equation 2.

$$x_i^{t+1} = x_i^t + \beta_o e^{-\gamma r_{ij}^2}\left(x_j^t - x_i^t\right) + \alpha_t \epsilon_i^t \quad .... (2)$$

Where x_i^{t+1} is the new position of firefly, x_i^t is the old position, $\alpha_t, \beta_o, \gamma$ are FA constant which are measure of randomness, attractiveness and scaling of fireflies. ϵ_i^t is a vector of random numbers drawn from a Gaussian distribution or uniform distribution at time t. If β0 = 0, it becomes a simple random walk. On the other hand, if γ = 0, it reduces to a variant of particle swarm optimisation. For the predefined number of iterations every time, position of firefly for which the error is minimum, is updated and mean of error is calculated. At the end the gain values for which the error has reached to a minimum level and no more change is observed, will be considered as final tuned value of PI parameters which are fed to simulink model and reduction in disturbance is noted. The complexity of firefly algorithm lies with the fact that it has two inner loops when going through the population n, and one outer loop for iteration t. So the complexity at the extreme case is O(n2t). As n is small (typically, n = 40), and t is large (say, t = 5000), the computation cost is relatively inexpensive because the algorithm complexity is linear in terms of t. The main computational cost will be in the evaluations of objective functions, especially for external black-box type objectives. This latter case is also true for all metaheuristic algorithms. After all, for all optimisation problems, the most computationally extensive part is objective evaluations. If n is relatively large, it is possible to use one inner loop by ranking the attractiveness or brightness of all fireflies using sorting algorithms. In this case, the algorithm complexity of firefly algorithm will be O(nt log(n)). The parameters considered for the firefly tuning are tabulated in table 1.

Table 1: firefly parameters considered for our case

Number of fireflies	3
Alpha, beta, gamma	[0.94, 0.76, 0.1]
Search space dimension	2
Upper limit [Kp,Ki]	[100,6000]
Lower limit [Kp,Ki]	[50,4000]
Total number of iterations	10

Since firefly algorithm is bio inspired algorithm so the relevance of terminology to our technical HVDC terms are tabulated in table 2.

Table 2: terminology of firefly algorithm equivalent to HVDC controller

Firefly Terminology	**Equivalent technical term**
Search space dimension	No of tuning variables (Kp,Ki)
Objective function	Mean of error
Upper and lower limit	Limits of Kp and Ki
Firefly movement	Change in value of Kp and Ki

III. RESULTS

A complete simulink model developed for HVDC line and its controller is shown in figure 3. The reference HVDC model has been picked form mathworks which is under license to use free and modify. The controller used in this model is updated by firefly algorithm. A 500 MW (250 kV, 2 kA) DC linterconnexion is used to transmit power from a 315 kV, 5000 MVA AC network. The network is simulated by a LLR damped equivalent (impedance angle of 80 degrees at 60 Hz and 3rd harmonic). The converter transformer and the rectifier are modelled respectively with the Universal Transformer and Universal Bridge blocks The converter is a 6-pulse rectifier. It is connected to a 300 km distributed parameter line through a 0.5 H smoothing reactor LsR. The inverter is simulated by a simple DC voltage source in series with a diode (to force unidirectional conduction) and smoothing reactor LsI. The reactive power required by the converter is provided by a set of filters (C bank plus 5th, 7th and high pass filters; total 320 Mvar). A circuit breaker allows toapply a DC line fault on the rectifier side. Voltages sent to the synchronization system are filtered by 2nd order band pass filters. The whole control system is discretized (Sample time = 1/360/64 = 43.4 us).

The DC line current at the output of the rectifier is compared with a reference. The PI regulator tries to keep the error at zero and outputs the alpha firing angle required by the synchronizing unit. Inputs 3 and 4 of the current regulator allow to bypass the regulator action and to impose the alpha firing angle. As stated the controller parameters are optimised by firefly algorithm, to measure the efficiency and correctness of this optimisation a curve between the number of iterations and objective function value i.e. mean of error is plotted as shown in figure 4. The early graph settle to a minimum value, efficient is the optimisation. In this case a minimum error is settled to $7.5*10^{-2}$ after 15 iterations. The oscillation stability of optimised case is observed in terms of total harmonic distortion which is calculated by FFT analysis of current for 2 cycles starting at 0.23 seconds. A FFT graph for harmonics for optimised case and unoptimized case is shown in figure 5. As is clear from the figure the THD is reduced from 3.1008% from un-optimised one to optimised THD 2.994%. The error generated in both un-optimised and optimised cases is shown in figure 6. It clearly visualise the stability of oscialltions is more in case of optimised one. Similarly the settled DC current is shown in figure 7 for both cases. The firefly tuned case is settling the DC current to near reference value with less number of oscillations as compared to un optimised case.

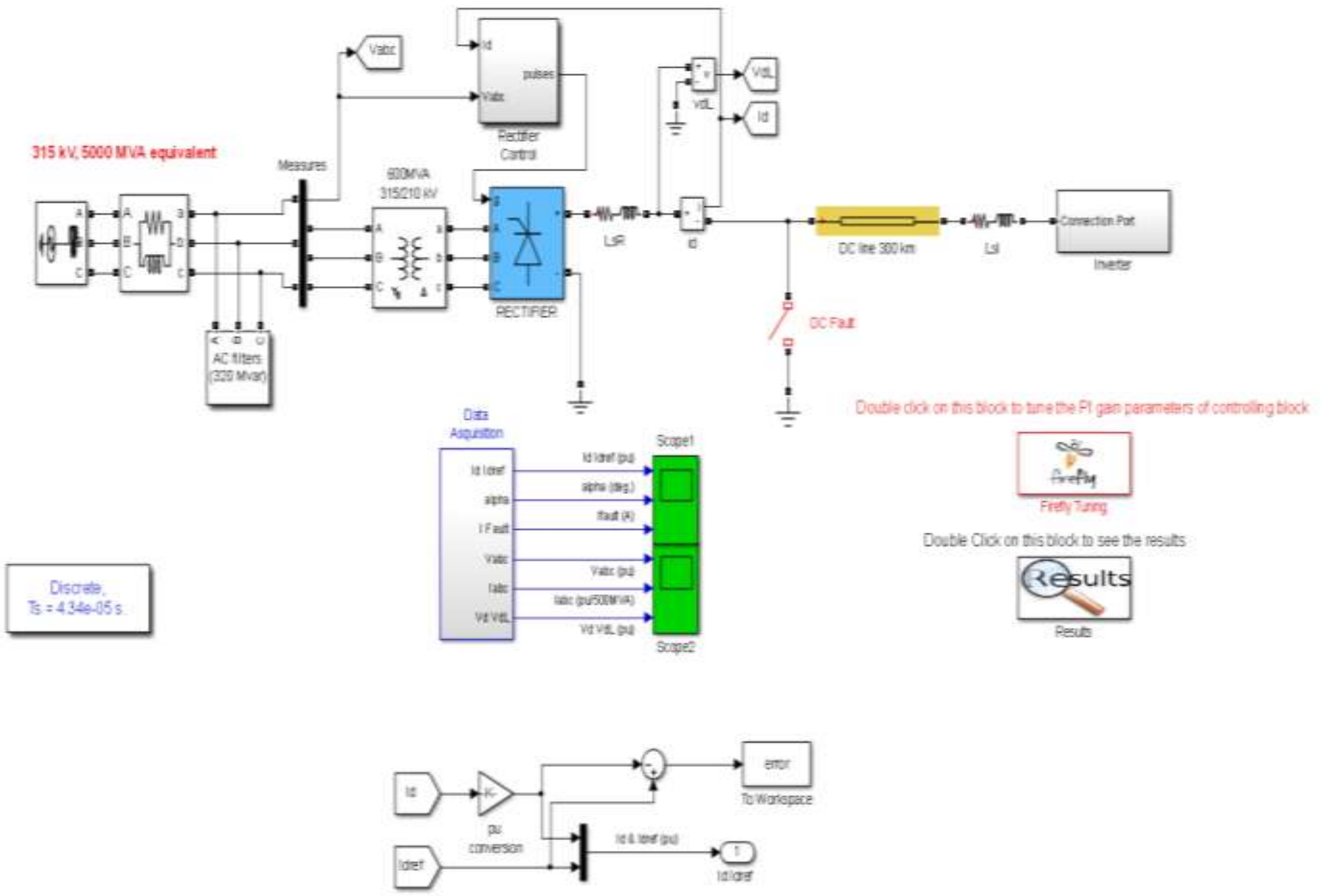

Figure 3: HVDC simulink model with its controller

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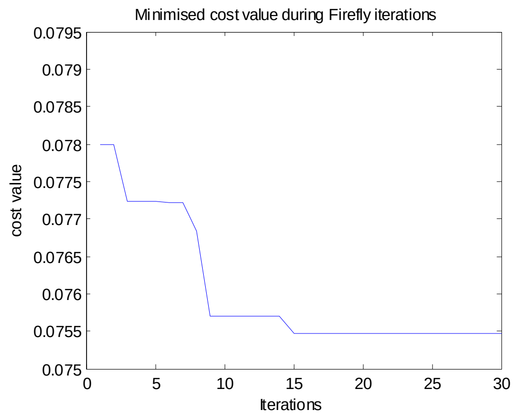

Figure 4: fitness function curve with number of iterations of firefly algorithm

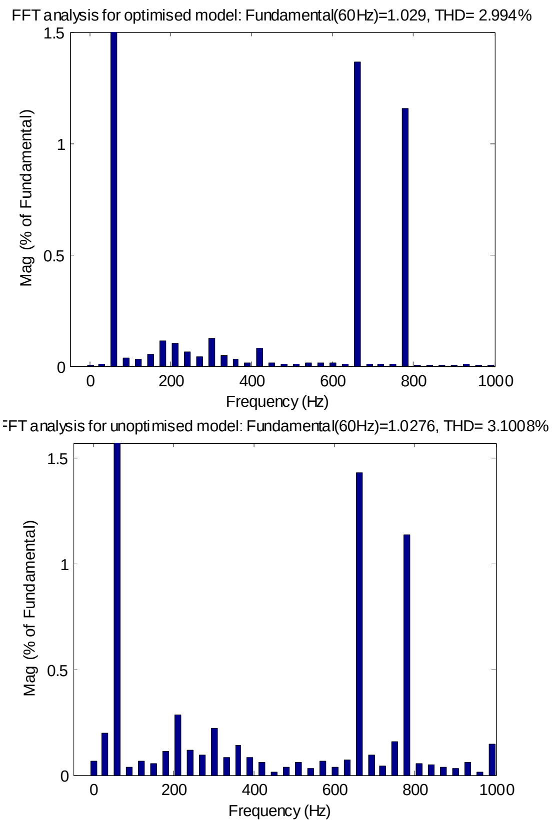

Figure 5: (a) optimised harmonics (b) un-optimised harmonics

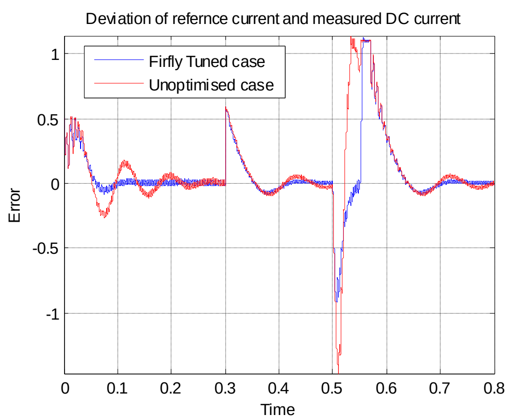

Figure 6: deviation of observed DC current to reference in optimised and un-optimised case

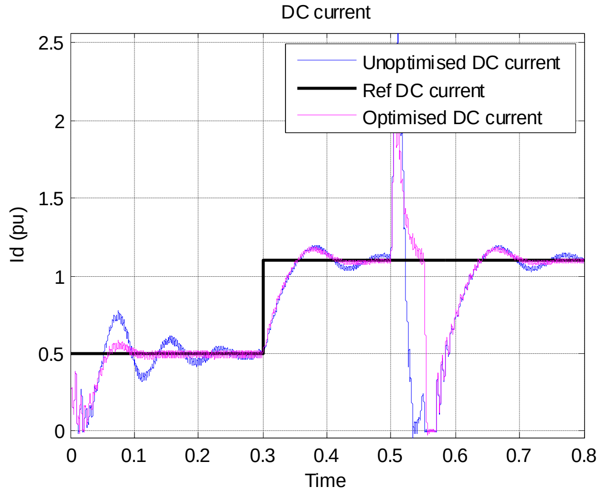

Figure7: DC current comparison

IV. CONCLUSION

In this paper a HVDC simulink model with PI controller is developed to stabilise the oscillations in the network when fault occurs. A DC fault at 0.5-0.51 sec is applied and firefly tuned PI controller is used to suppress these oscillations. Total harmonic distortion (THD) is used to evaluate the performance of proposed scheme. The THD obtained in firefly tuned PI controller is 2.994% whereas in conventional PI case it is 3.1008% for the same fault interval. This THD is obtained by FFT analysis of current waveform for 2 cycles starting at 0.23 seconds. This number proves that firefly tuned PI controller performs better than conventional controlling scheme.

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