Dynamic Stability Improvement of VSC-HVDC Connected Multi machine Power System by Spider Monkey optimization Based PI controller

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Abstract— **This paper presents the application of spider monkey optimization based PI controller to a VSC-HVDC based four machine power system. A PI controller, whose gains are selected by spider Monkey optimization technique, is used to minimize the power oscillations and to recover the dynamic stability of VSC-HVDC based four machine power systems. The proposed optimized PI controller is tested under different faults like three phase LLLG fault, Change of torque angle, etc. The comprehensive simulations are carried out in time domain in MATLAB/SIMULINK environment.**
The following figures depicts that optimized PI controller is more efficient than conventional PI controller.

Index Terms- Nonlinear, VSC-HVDC, Spider Monkey Optimization.

I. INTRODUCTION

In present scenario the most challenging work that to deliver power with AC expansion heavily loaded network satisfying the stability problems. Under disturbance the hasty control of active & reactive power of VSC-HVDC system can improve the power system efficiency. In case of Sevier fault quick power run back and power reversal is essential to maintain synchronization of power operation [1-3]. VSC-HVDC system also capable to afford efficient damping to allay electromechanical oscillations by active and reactive power modulation. Many advanced control theory can be applied in VSC-HVDC system for improvement of dynamic performance of AC network. [4-5].

In this paper an attempt has been made regarding the above approach. The potential of all controllers are normally achieved through PI controller. PI controllers does not perform properly over a broad range of operating condition. Many researchers presented the mathematical modeling and control approach to the VSC-HVDC system, such as small signal stability analysis[6-7], feedback linearization application to decoupled control of converter[8]and application of adaptive control[9].

Many of these works have studied a decoupled VSC-HVDC system that is without considering a parallel AC line. In spite of some research has been conducted for VSC-HVDC with parallel AC line, a lot of aspects are yet to be studied comprehensively. Also the previous papers have neglected many important features in operation of HVDC system. In specific related to HVDC and HVAC interactions. In this study, a PI controller tuned by spider monkey optimization technique, is applied to the VSC-HVDC transmission systems in order to improve the dynamic stability under broad area of operating conditions. The computer simulations are carried out MATLAB software package. The simulation results explain that the controllers contribute thoroughly to recover the dynamic behavior, improve the system stability and damp the undesired oscillations.

The structure of rest part the paper is arranged in six sections as follows. In section II, mathematical modeling of the VSC-HVDC based four machine power system is presented. In section III, the spider monkey optimization technique is explained. In section-IV. Simulation results that illustrates the usefulness of the proposed strategies in section V. At last, conclusions are drawn in Section V

II. MATHEMATICAL MODELLING OF VSC- HVDC SYSTEM

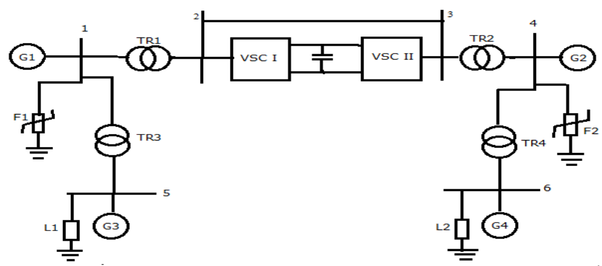

Figure.1. two-area decoupled AC-VSC-HVDCsystem

A typical VSC-HVDC system which connects two areas. The HVDC link consists of two converters. One is a rectifier and the other operates as the inverter station as shown in Figure.1 ~~The~~ two areas are connected by a short transmission line. The reactance of the short lines are x_{12} and x_{15} in the area-1 and x_{24} and x_{26} in area-2. The impedances of the converter and the inverter are $r_r + jx_r$, and $r_i + jx_i$, respectively. . r_{dc} is the DC link resistance, and inductance l_{dc} . P_{L1} , Q_{L1} and P_{L2} , Q_{L2} are the loads in the area-1 and area-2, respectively. The DC link capacitor C_{dc} used at each station maintains a constant DC voltage. The synchronous generator is represented by a third order model and is equipped with an AVR and PSS.

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A. Synchronous MachineModel

The fourth order model of the synchronous machine equipped with a automatic voltage regulator (AVR) for excitation control is considered for this study. We are investigating the efficiency the VSC-HVDC control. The mathematical representation of the dynamics of the synchronous machine is as follows:

$$\frac{d\delta_1}{dt} = \omega_1 - \omega_{10}$$

$$I_{c1}\frac{d\omega_1}{dt} = (P_{m1} - P_{e1})$$

$$T'_{d1}\frac{dE'_{q1}}{dt} = \left(\Delta E_{fd1} + E_{fd1} - E'_{q1} - \left(x_{d1} - x'_{d1}\right)I_{1d}\right) \tag{1}$$

$$\frac{1}{K_{e1}}\frac{d\Delta E'_{f1}}{dt} = -\Delta E'_{f1} + \frac{1}{T_{e1}}\left(V_{t1ref} - V_{t1}\right)$$

Where, P_{m1} and P_{e1} are the mechanical and electrical powers of the generators, M and D are the inertia constant and damping coefficient respectively; ω_1 and δ_1 are the generator speed and rotor angle respectively; E'_{q1} and E_{fd1} represents the generator internal voltage and field voltages respectively. T'_{d1}, K_{e1} and T_{e1} are the open circuit field time constant, excitation gain and time constant ; x_{d1} and x'_{d1} are the direct axis reactance.

B. Rectifier

The dynamic equations of rectifier are

$$\frac{dI_{rQ}}{dt} = \frac{-r_r}{l_r}I_{rQ} - \omega_1 I_{rD} + \frac{V_{1Q}}{l_r} - \frac{V_{rQ}}{l_r} \tag{2}$$

$$\frac{dV_{dc1}}{dt} = \frac{P_{dc1}}{C_{dc}V_{dc1}} - \frac{I_{dc}}{C_{dc}} \tag{3}$$

C. Inverter:

$$\frac{dI_{iD}}{dt} = \frac{-r_i}{l_i}I_{iD} + \omega_2 I_{iQ} - \frac{V_{2D}}{l_i} + \frac{V_{iD}}{l_i} \tag{4}$$

$$\frac{dI_{iQ}}{dt} = \frac{-r_i}{l_i}I_{iQ} - \omega_2 I_{iD} - \frac{V_{2Q}}{l_i} + \frac{V_{iQ}}{l_i} \tag{5}$$

Where $I_{rD}, I_{rQ}, V_{1D}, V_{1Q}$ and $I_{iD}, I_{iQ}, V_{2D}, V_{2Q}$ are the voltage and currents. The corresponding impedances on the rectifier and inverter sides are $r_r + jx_r$ and $r_i + jx_i$. The dc link voltage, current and the capacitance are V_{dc1}, V_{dc2}, I_{dc} and C_{dc} respectively. In equation (4&5) the system equations can be rewritten as

$$\frac{dI_{rD}}{dt} = \frac{-r_r}{l_r}I_{rD} + \omega_1 I_{rQ} + \frac{V_{1D}}{l_r} - \frac{u_1}{l_r} \tag{6}$$

$$\frac{dI_{rQ}}{dt} = \frac{-r_r}{l_r}I_{rQ} - \omega_1 I_{rD} + \frac{V_{1Q}}{l_r} - \frac{u_2}{l_r} \tag{7}$$

$$\frac{dV_{dc1}}{dt} = \frac{(V_{1D}I_{rD} + V_{1Q}I_{rQ} - r_r(I_{rD}^2 + I_{rQ}^2))}{C_{dc}V_{dc1}} - \frac{V_{dc1} - V_{dc2}}{R_{dc}C_{dc}} \tag{8}$$

$$\frac{dI_{iD}}{dt} = \frac{-r_i}{l_i}I_{iD} + \omega_2 I_{iQ} - \frac{V_{2D}}{l_i} + \frac{u_3}{l_i} \tag{9}$$

$$\frac{dI_{iD}}{dt} = \frac{-r_i}{l_i}I_{iQ} - \omega_2 I_{iD} - \frac{V_{2Q}}{l_i} + \frac{u_4}{l_i} \tag{10}$$

III. SPIDER MONKEY OPTIMIZATION ALGORITHM

It is a stochastic optimization technique which developed from the concept of community activities of spider monkeys. It is a fusion-fission social configuration (FFSC) based on foraging actions of spider monkeys.

1.The fission –It is a social configuration in which animals are social and like to live in a group of 40-50 members. In order of search food FFSC reduces the foraging aggression among group members by dividing them into sub-groups.

2. A female spider monkey is assigned as in charge for searching food sources. So it is designated as group leader. In case of failure of the group leader in searching food, she divides into smaller subgroups containing 3to 8 members. The subgroup forages separately.

3. Sub groups are pilot by a female local chief, who becomes decision-maker for preparation an proficient foraging route each day.

4. The information about availability of food sources are communicated by the members of subgroups within protective boundaries. In the enlarge strategy, the foraging behavior of FFSC based spider monkeys is divided into four steps.

Step-1: The group initiates foraging after the distance from the food is estimated.

Step2: Taking into account the distance from the food, group members modify their position and further assess distance from the food sources.

Step-3: Within the group the local head update its finest position. In case the location is not updated in a particular time, then all individuals of that cluter start food searching in random direction.

Step-4: The best position of global leader is updated. Further in stagnant condition it is splits into smaller size subgroup

Figure.2.Social Organization and Behaviour (a) Spider-Monkey (b). Spider Monkey Group (c) Spider Monkey sub-group (d) foods foraging

In the fourth step, when the global leader gets trapped, it divides the groups into smaller subgroups for foraging of foods .This phenomena presents division of labor property. The decision of global leader depends on negative feedback given by LLL and GLL.

However, the anticipated approach is motivated from the foraging behavior of spider monkeys ,that is unlike the expected foraging comportment of spider monkeys. In this policy, the position of leader (local or global) is not fixed but depends upon the capacity of leader to search of food. Further the spider monkeys communicate themselves by different communication technique which is not included in the proposed strategy. This is how the proposed tactic is special from the real foraging behavior of spider monkeys.

A. Spider Monkey Optimization Algorithm (SMO)

It is alike other population-based algorithms, SMO is trial and error based mutual computational process. The SMO process consists of six phases: initialization of population, Local leader phase, Global leader phase, Local leader decision phase and Global leader decision phase. The details of each step of SMO implementation are described below:

Phase-1. Initialization of the population:

Primarily, SMO generates a unvaryingly distributed initial population of N number of spider monkeys where each monkey $M_i(i=1,2,...,N)$ is a vector of dimension D. The number of variables in the optimization problem is D and M_i is the i^{th} spider monkey in the population. Each spider monkey M corresponds to the potential solution of the problem under consideration. Each M_i is initialized as follows:

$$M_{ij}=M_{\min j}+U(0,1)(M_{\max j}-M_{\min j}) \quad (11)$$

Where $M_{\min j}$ and $M_{\max j}$ are bounds of M_i in j^{th} track and $U(0,1)$ is a random number in the range [0,1] distributed uniformly.

Phase-2. Local Leader Phase (LLP)

Position of each spider monkey M is modifies by from the expertise of local leader as well as group members. The new position fitness is evaluated. The spider monkey updates its position only when the fitness value of current position is higher than that of older position. The update equation for i_{th} monkey, which is belongs to k_{th} local group is given by

$$M_{new_{ij}}=M_{ij}U(0,1)(LL_{kj}-M_{ij})+U(-1,1)(M_{rj}-M_{ij}) \quad (12)$$

Where M_{ij} is the j_{th} dimension of the k_{th} local group leader position. M_{rj} is the jth dimension of the r_{th} M which is chosen randomly within k_{th} group such that $r \neq i, U(0,1)$ is a uniformly distributed random number between 0 and 1.

Phase-3. Global Leader Phase (GLP)

Global leader phase starts after the Local Leader Phase, all the monkeys revise their position using potential of global leader and experience of local group group members.

The position update equation for this phase is as follows:

$$M_{new_{ij}}=M_{ij}+U(0,1)(GL_j-M_{ij})+U(-1,1)(M_{rj}-M_{ij}) \quad (13)$$

Where GL_j is the jth dimension of position of Global leader and $j \in \{1,2,...,D\}$ is an index, chosen randomly.

In this phase, the spider monkey position is updated which depends on a probability p_i which are intended using their fitness. In this way a efficient candidate will have a greater chance to make itself better. The calculation of probability uses following expression.

$$p_i=0.9\frac{f_i}{\max\_fi}+0.1, \quad (14)$$

Where f_i signifies the fitness value of the i_{th} spider monkey. Further, the fitness of the offspring position of the monkeys is compared calculated and with the previous position and corresponding better position is adopted.

Phase- 4. Global Leader Learning (GLL) phase

In this phase, the position of global leader is reorganized by applying the insatiable assortment process in the population i.e, the position of the spider monkey having finest fitness in the population is selected as the restructured site of the global leader. Further, it is confirmed whether the position of global leader is updating or not and if not then the global limit count is incremented by 1.

Phase-5. Local Leader Learning (LLL) phase

Here the position of the local leader is modified by applying the avaricious selection within that group i.e, the location of the spider monkey having the most appropriate fitness in that cluster is selected as the updated position of the local leader. Further, the upgraded version of the local leader is weigh against the old one and if the local leader is not updated then the Local Limit Count is incremented by 1.

Phase-6. Local Leader Decision (LLD) phase

If the position of the local leader is not updated up to a preset verge called Local Leader Limit, then all the members of that group revise their positions either by random initialization or by using combined information from global leader and local leader which is given by the following equation.

$$M_{new_{ij}}=M_{ij}+U(0,1)(GL_j-M_{ij})+U(0,1)(M_{ij}-LL_{kj}) \quad (15)$$

From Eq. (15) it is understood that the updated dimension of the SM is attracted towards global leader and repels from the local leader.

Phase-7. Global Leader Decision (GLD) phase

In this phase, the global leaders position is evaluated and if it is not updated into a preset number of iteration, called global leader limit. Then many smaller groups are generated by the global leader till the maximum number of groups (MG) are formed. In the new groups local leader is elected by GLD phase. If the position of the global leader is not updated even after increasing the number of groups then the global leader combines all the group to form a single group. The proposed algorithm is motivated from the fission-fusion structure of SMS.

IV. PI CONTROLLER

Due to easy operation, simplicity in structure and robust in nature, the PI controller is widely used in power system controller. The largest PI controller implementation is based on digital design. The drawback of PI controller is to select the gains properly. The performance such as rise time, settling time and steady state error depends on the gains of the controller. The mathematical representation of PI controller is given by

$$y(t) = k_p er(t) + k_i \int_0^t er(t)dt \quad (16)$$

Where k_p and k_i are the gains of PI controller.

The PI controller for converter and inverter are given by

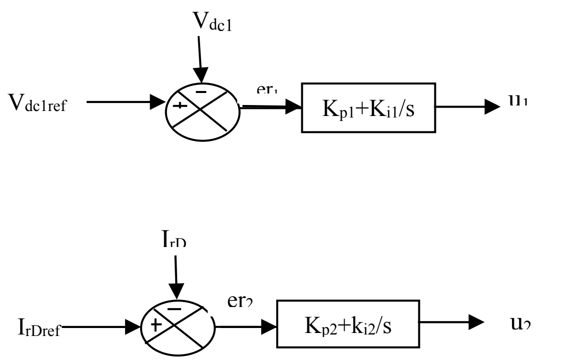


Figure.3 PI controller for Converter station

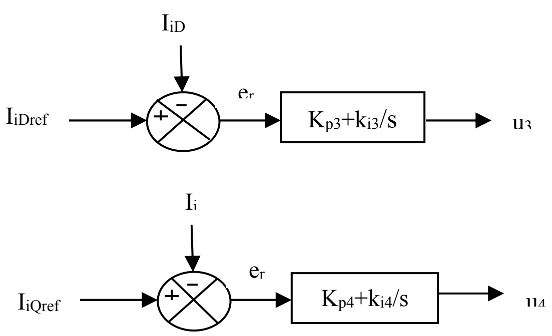


Figure.4. PI controller for Inverter station

V. OPTIMIZED PI CONTROLLER

The hit and trial selection of PI control gains do not improve the performance of the system. The performance like settling time, over shoot and steady state error improved by selecting the optimized gains of the PI controller. The structure of optimized PI controller (SPMPI) is shown as bellow.

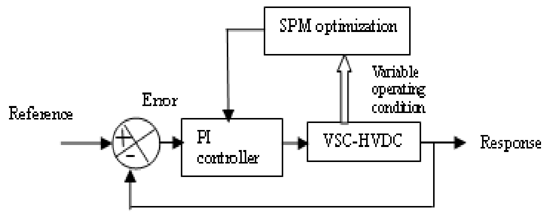


Figure.5 Structure of SPMPI Controller.

VI.SIMULATION RESULT

The four machine power system model is simulated with MATLAB, under different fault conditions. The performance of the SPMPI controller is shown in rotor angle oscillation, rotor speed, inter area oscillations which are depicted in the following cases

Case-1:

The system is simulated with a LLLG fault at bus-1 from 1 sec to 1.2 second. The performance of the SPMPI controller restores the system earlier than the conventional PI controller. The performance improvement with the new controller is shown in Fig.

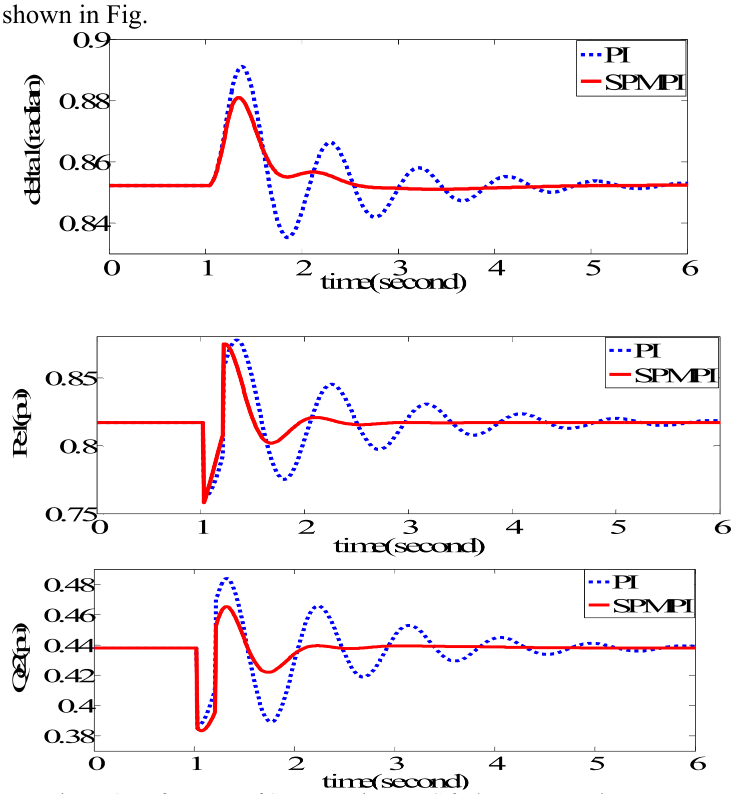


Figure.6. Performance of SPMPI under LLLG fault at converter bus

Case-2:

With the same operating condition as in case 1, a step change in the active power is introduced whose response is shown in figure 7. The results depicts that the response is very fast and error is minimum in attaining the steady state value. The impact on the reactive power is also minimal.

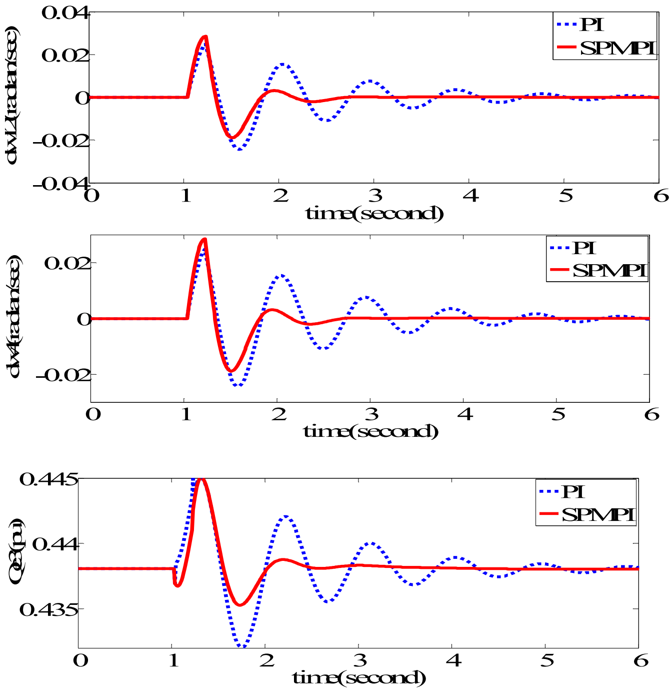
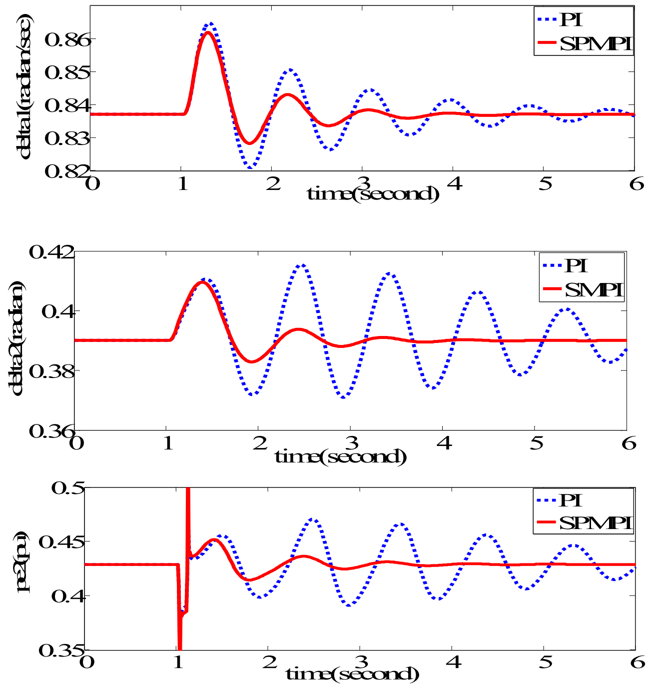


Figure.7. Performance of SPMPI under step change in active power

Case-3:

In this case the robustness of the proposed controllers are tested under a disturbance created by 20% increase of mechanical input of generator-1, and then simulated. Due to increase of generator input the performance of the system is affected by PI controller, where as the disturbance is minimum in case of SPMPI controller.



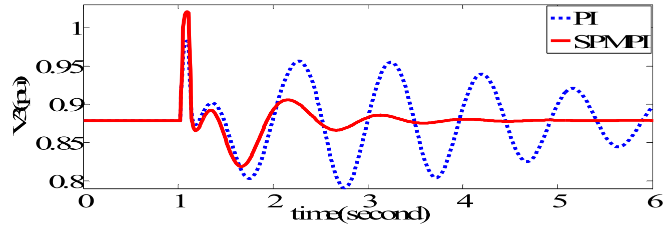
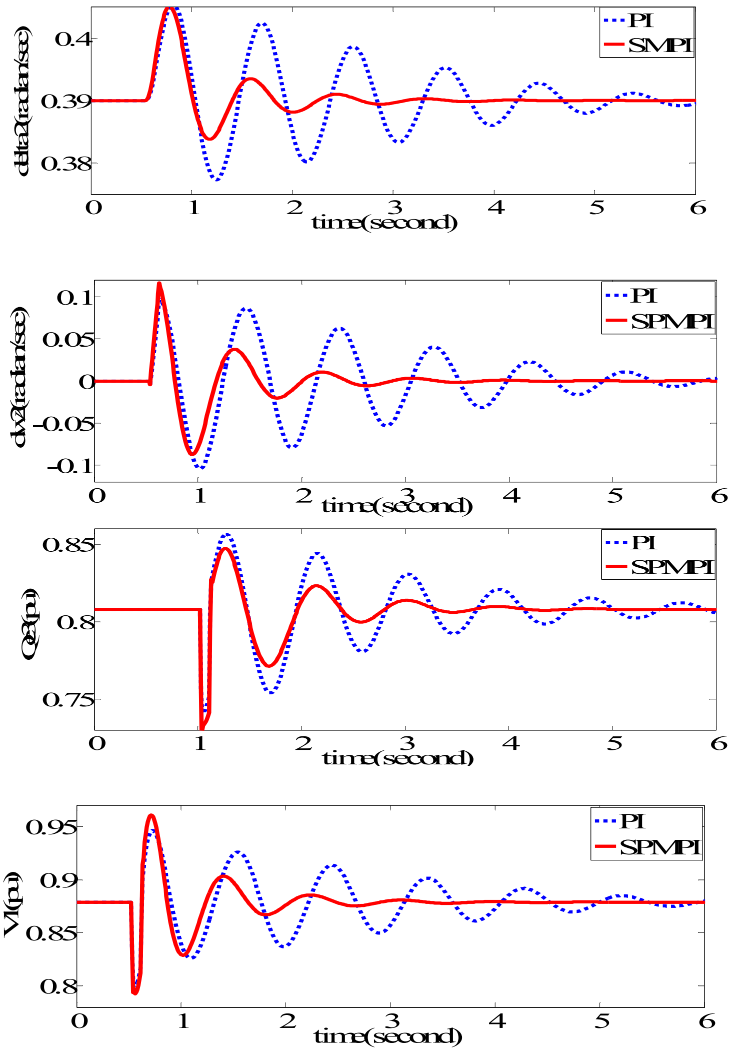


Figure.8. Performance of SPMPI under 20% increase of Mechanical input of generator-1.

Case:4

To study the robustness of the proposed controller, A fault was created near the converter DC bus and sustains from 1 sec to 1.2 second. The rotor angle, generator active and reactive power and the rotor oscillations are depicted in Figure. From the figure it is evident that the recital of the HVDC system is very vigorous and practically the excursions in the various states are completely minimal, whereas the performance of the SPMPI is better. The operating condition chosen for the simulation of DC fault is P_r= 0.7 Pu, Q_r = 0.45 Pu, P_i =0. 36 Pu, Q_i= 0.2pu.



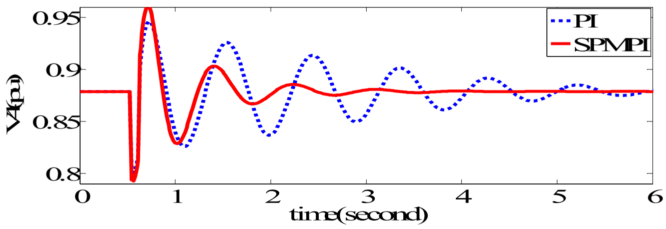


Figure.9. Performance of SPMPI under DC bus fault

VII. CONCLUSION

In this paper mathematical model of a multi machine power system, based on VSC-HVDC link is developed. A spider Monkey Optimization technique based PI controller is applied. The controller proposed in this paper is found to be robust and produce significant damping, less over shot, small settling time under different operating condition. This controller proved its' efficiency during different fault condition. The simulation results clearly reveal that the SPMPI significantly contributes to improve the dynamic stability.

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