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Optimization PI Controller Parameters For VSC-HVDC System based on Particle-Swarm-Optimization

تحسين قيم عناصر متحكم المعامل الطردي والتكاملي لمحول مصدر جهد عالي التيار المستمر بتعظيم سرب الجسيمات

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KEYWORDS:
Optimization; HVDC-VSC; DC-link; PI; PSO. MATLAB, Simulink.

الملخص ـ في وقتنا الحاضر تعتبر أنظمة الجهد العالي ذو التيار المستمر من المكونات الرئيسية في الشبكات الكهربية لقدرتها على حل كثير من المشاكل : مثل المشاكل المتعلقة بالربط بين الشبكات مختلفة التردد . ومن المعروف أن استقرار هذه الشبكات هدف هام ولذلك يسعى كثير من الباحثين لتقديم حلول لهذه الظاهرة. فهناك طرق تقليديه يتم استخدام المتحكم ذو المعامل الطردي والتكاملي لهذه الشبكات . حيث يتم فرض قيم عناصر المتحكم ذو المعامل الطردي والتكاملي بناء على الخبرة الذاتية للأشخاص . وفى هذا البحث تم تحسين هذه القيم باستخدام طريقة تعظيم سرب الجسيمات وبعد ذلك تم عمل مقارنه بين النظامين المحسن والعادي حيث أثبتت النتائج كفاءة النظام المقترح .

***Abstract*— Nowadays the HVDC systems are considered as basic devices in the new electrical networks because they could solve many problems such as connections of different frequencies regions. Networks stability is the aim of many researchers. They used conventional methods such as PI controllers for this purpose in these methods. The parameters of PI controllers were assumed depending on the operator's experiences. The authors of this paper optimized the system parameters using Particle Swarm Optimization (PSO). A comparative study between the conventional and optimized systems will be presented. The obtained results show the efficient performance of the designed system**

I. INTRODUCTION

The continuous increasing of demand electrical power causes many problems of the generation, transmission and distribution network's area. It's found that High Voltage Direct Current (HVDC) devices could solve many of these problems. They can be included in many power systems such as long distance bulk power delivery and connection of non-synchronous plants. [1][2].

The two main types of converters are Current Source Converter (CSC) and Voltage Source Converter (VSC). The CSC type suffers from many problems such as commutation failure and bad performance especially in weak AC system. VSC has many advantages. It presents fast damping oscillations and good transient stability. It also feeds passive systems in absence of generation source [3]-[7].

The optimal type of VSC can be obtained by using Particle Swarm Optimization PSO technique which realizes a favorable experiment result [8].

The control over active and reactive current components of a VSC-HVDC is normally achieved through a PI controller. The PI controller has many problems such as the impairment of providing suitable control and transient stability enhancement. There are several searches efficient methods for resolving complex power system problems. One of these methods is PSO which is a very simple and effective method.

This paper introduces the ability of control of the active and reactive power and DC voltage for the electrical systems. The PI controller is used to improve the system stability. The

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values of PI parameters play an important role in achieving the stability. In conventional method the PI parameters are chosen depending on the operator's experience. But in the proposed study the parameters are optimized by PSO [9].

In this paper, the models of two machines infinite bus electric power system are installed with the parameters of the VSC-HVDC damping controller optimized by PSO in MATLAB encoding. The paper is arranged in six major parts. The connections and controller of VSC-HVDC are presented in section II, III. PSO will be discussed in section IV. System performance and results discussion and conclusion will be found in section V, VI.

II. VSC-HVDC Connections

The studied system consists of AC breakers, AC filters, transformer, phase reactor, voltage source converters, DC capacitor and DC cable to connect it to another station or grid. Figures 1 and 2 explain the MATLAB simulation model of the VSC transmission system.
The studied system can be divided into two sides AC and DC.

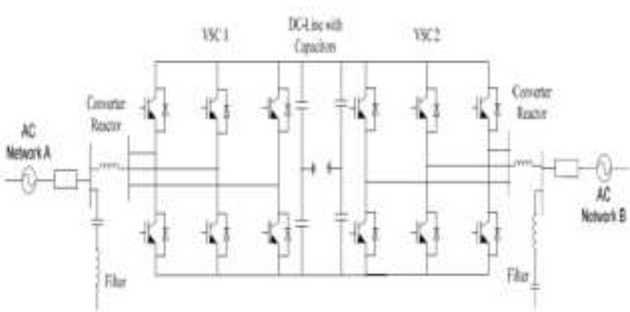

Fig 1 VSC-based HVDC system

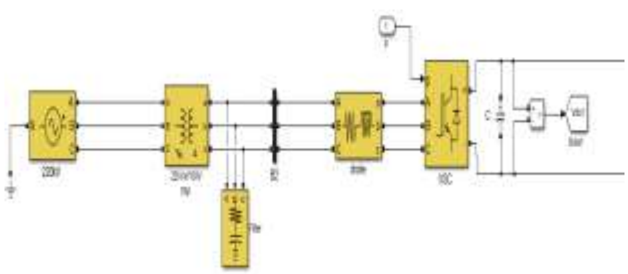

Fig 2 VSC-HVDC MATLAB simulation model

A) AC side

The AC side can be considered as a controllable voltage source using pulse width modulation PWM technique where it's able to control independently the frequency, the phase and amplitude of its AC voltage. The equivalent circuit of this side is shown in Figure 3.

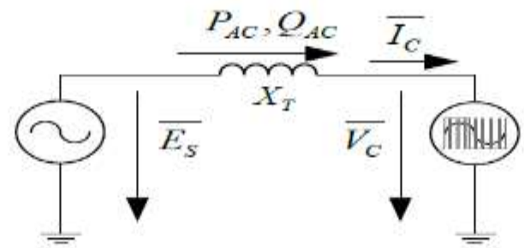

Fig 3 Equivalent circuit for the AC side of a VSC-HVDC

If the transformer and reactor resistances are neglected the active power flow and reactive power flow can be formulated, in PU by equations 1, 2

$$P_{ac} = \frac{E_S V_c}{X_T} \sin \delta \qquad (1)$$

$$Q_{ac} = \frac{{E_S}^2 - E_S V_c \cos \delta}{X_T} \qquad (2)$$

Where P_{ac} and Q_{ac} is the active and reactive power in the ac system with voltage magnitudes E_s and V_c between two electrical nodes. The variables δ and X_T are the phase-angle difference and line reactance between the two nodes respectively [10].

From equation 2 if the real component of the VSC output voltage $V_c(\cos\delta)$ has a smaller magnitude than the voltage of the AC system, the converter will consume reactive power from the AC network. Otherwise the converter will provide reactive power to the network. Figure 4 shows the phasor diagram for the AC side of a VSC-HVDC station.

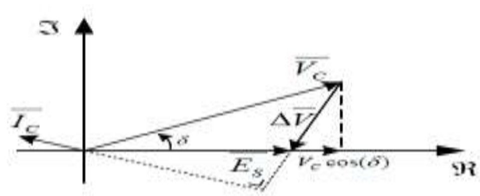

Fig 4 Phasor diagram of a VSC

B) DC side

The DC side of the converter is modelled as controllable DC current source. The DC current can be calculated by equation 3 based on the power balance between the AC and DC sides of the converter (disregarding converter losses):

$$p_{AC} \approx p_{DC} = V_{DC}.I_{DC} \Rightarrow I_{DC} = \frac{P_{DC}}{V_{DC}} \qquad (3)$$

Where P_{DC}, V_{DC} and I_{Dc} are the power, the voltage and the current on the DC side. The equivalent circuit for the DC side of a VSC-HVDC is presented in Figure 5.

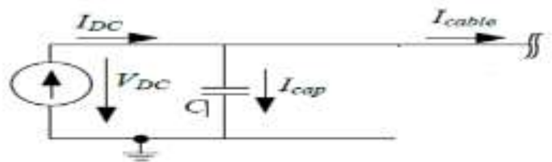

Fig 5 Equivalent circuits for the DC side

III- VSC-HVDC CONTROLLER

The VSC-HVDC using PWM technique can control the active and reactive power independently through two independent paths shown in Figure 6.
The active power can be used to control the DC voltage and the frequency of the AC side. The reactive power can be used to control the AC voltage value.

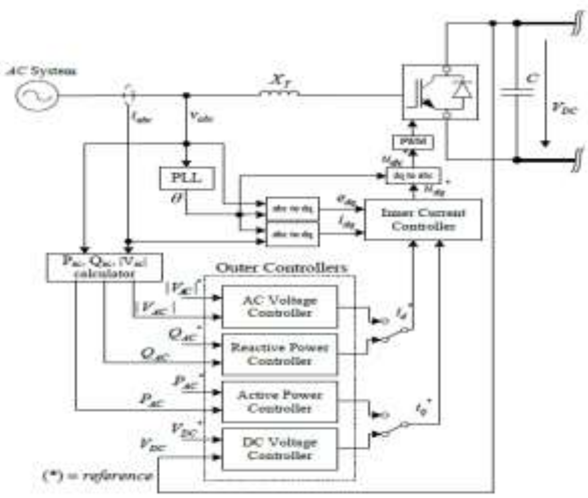

Fig 6: VSC-HVDC Control Scheme

A) OUTER CONTROLLER

The outer controllers are responsible for generating and providing the reference currents ($i_d{}^*$ and $i_q{}^*$) to Inner Current Control ICC. These controllers can be categorized in two distinguished groups: active power path and reactive power path. For the active power path the DC voltage and active power controllers will be applied and they will provide the current reference for the q-axis. For the reactive power path, the AC voltage and reactive power controllers will be implemented and these will be responsible of generating the current reference of the d-axis. In every controller a PI regulators employed to annul steady state errors.

1- ACTIVE AND REACTIVE POWER CONTROLLERS

If the Park-Transformation that conserves power is used and if the three-phase system is balanced, the expressions for the calculation of the active and reactive power above in the dq frame are given by:

$$p_{ac}=e_d i_d+e_q i_q \qquad (4a)$$

$$q_{ac}=e_q i_d-e_d i_q \qquad (4b)$$

$$i^*{}_d=(q^*{}_{ac}-q_{ac}).\left(k_{p,q}+\frac{k_{i,q}}{s}\right) \qquad (5a)$$

$$i^*{}_q=(p^*{}_{ac}-p_{ac}).\left(k_{p,p}+\frac{k_{i,p}}{s}\right) \qquad (5b)$$

Where e_d *and* e_q are the voltage at the PCC in the (dq) frame in pu, i_d*and* i_q are the Current of the converter in the (dq) frame in pu, $q^*{}_{ac}$ is reference of the reactive power at the AC side of the converter in pu, $p^*{}_{ac}$ is the reference of the active power at the AC side of the converter in pu, $k_{p,q}$ is the proportional gain of the reactive power PI regulator, $k_{p,p}$ is proportional gain of the active power PI regulator , $k_{i.q}$ is the integral gain of the reactive power PI regulator and $k_{i,p}$ is integral gain of the active power PI regulator respectively.
The PI controller for active power and reactive power are shown in Figures 7 and 8.

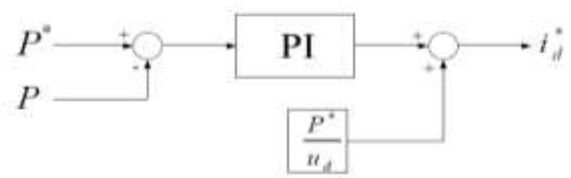

Fig 7 Active power controller

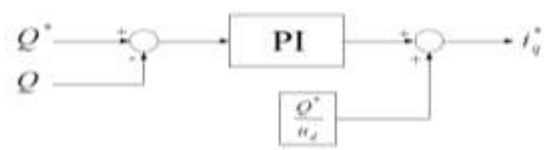

Fig 8 Reactive power controller

2- DC VOLTAGE CONTROLLER

The objective of this controller is to maintain the DC voltage at its reference value by regulating the active power exchanged with the AC grid by regulating $i_q{}^*$.

A DC voltage controller that operates on the error between the DC voltage and its reference value could be applied. However, if the controller operates linearly on the DC voltage, the closed-loop dynamics will depend on the operating point [11].

The DC voltage outer controller is made to operate by the energy, w_c stored in the VSC-HVDC station capacitor. The output current can be calculated by equation 6.

$$i^*{}_q=(w^*{}_c-w_c).\left(k_{p,w}+\frac{k_{i,w}}{s}\right) \qquad (6)$$

where $\boldsymbol{w}^*_{\boldsymbol{c}}$ is DC capacitor's energy reference, $\boldsymbol{w}_{\boldsymbol{c}}$ energy stored in the DC capacitor, $k_{p,w}$ is proportional gain of the DC voltage PI regulator and $k_{i,w}$ is integral gain of the DC Voltage PI regulator respectively.

3- AC VOLTAGE CONTROLLERS

The AC voltage controller regulates the amplitude of the AC voltage at the Point of Common Coupling PCC at a given reference value by modifying the current reference of the d-axis, $i_d{}^*$ as shown in Figure 9. This suggests that the controller commands the converter to transmit an amount of reactive power so that the AC voltage at the PCC matches the given reference value. The output current can be calculated by equation 7

$$i^*{}_d = \left(\left|e^*_{dq}\right| - \left|e_{dq}\right|\right).\left(k_{p,v} + \frac{k_{i,v}}{s}\right) \qquad (7)$$

Where $e^*{}_{dq}$ is the reference of the voltage at the PCC in the (dq) frame in pu, $k_{p,v}$ is proportional gain of the AC voltage PI regulator and $k_{p,i}$ is integral gain of the active power PI regulator

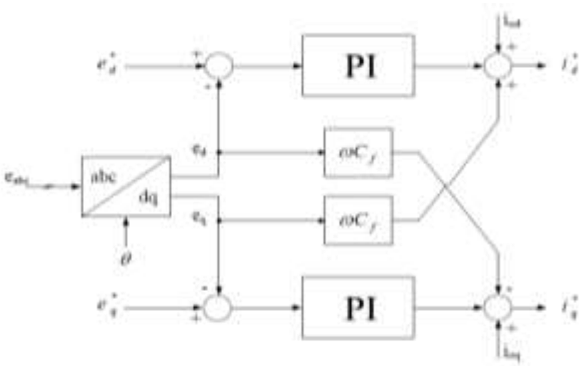

Fig 9 AC voltage controller

B) INNER CURRENT CONTROLLER ICC

Ordinarily in ICC, the converter currents and the AC three-phase voltages are transformed to the rotating direct-quadrature dq coordinate system. (Considering the phase reactor and transformer losses). The error voltage can be calculated by the following equation

$$e_s - v_c = R_T.i_c + L_T.\frac{d}{dt}(i_c) \qquad (8)$$

Equation 8 can be written in the dq reference frame by Park Transformation as follow:

$$e_d - v_d = R_T.i_d + L_T.\frac{d}{dt}(i_d) - wL_{T.}i_q \qquad (9a)$$

$$e_q - v_q = R_T.i_q + L_T.\frac{d}{dt}\left(i_q\right) + wL_{T.}i_d \qquad (9b)$$

Where R_T and L_T represent respectively, the total resistance and inductance between the converter and the PCC with the AC network as shown in Figure 10.

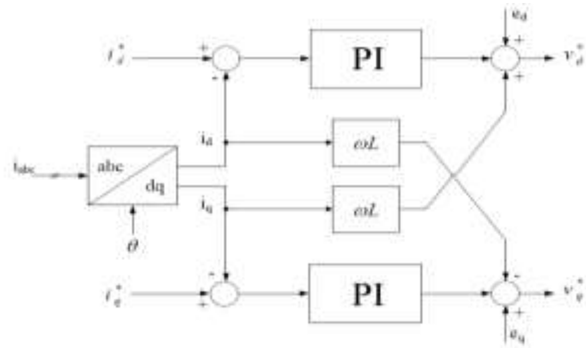

Fig 10 The structure of the inner current controller

IV. PARTICLE SWARM OPTIMIZATION (PSO)

PSO algorithm was invented in 1995 by Eberhart and Kennedy. PSO simulates a swarm of individuals or particles fly through limited search space area.

PSO simulates the behavior of flocks of birds, swarm of fish when are seeking for their food [12]-[15].

Each particle has its own position and speed. The particle position is modified continuously according to the best position found itself and the swarm.

Each particle in the swarm is represented by the following characteristics. If the v_i is the current velocity of the particle, x_i *is* the current position of the particle, y_i is the personal best position of the particle. $\hat{y}$ is the neighborhood best position of the particle . Let F denote the objective function, t is the time of the objective function and s denotes the size of the swarm. When the personal best of a particle at time step t is upgraded for the *gbest model*, the best particle is determined from the entire swarm by selecting the best personal position. When the position of the global best particle is denoted by the vector $\hat{y}$:

$$y_i(t+1) = \begin{cases} y_i(t) \quad if\ F(x_i(t+1)) \geqslant F(y_i(t)) \\ x_i(t+1)\ if\ F(x_i(t+1)) < F(y_i(t)) \end{cases} \qquad (10)$$

$$\hat{y} = \in \{y_0, y_1, y_2, \ldots\ldots, y_{s-1,}y_s\} \qquad (11)$$

Where:

$$\hat{y} = min\{F\left(y_0(t), \ldots\ldots F\left(y(t)\right)\right\} \qquad (12)$$

The velocity update step is specified for each dimension, v_{ij} represents the j^{th} element of the velocity vector and the i^{th} of the particle. The velocity of particle i is updated using the following equation

$$v_{i,j} = w.v_{i,j}(t) + C_1.\Delta_1 + C_2.\Delta_2 \qquad (13)$$

Where:

$$\Delta_1 = r_{1,j}.(y_{i.j}(t) - x_{i,j}(t)) \quad (14)$$

$$\Delta_2 = r_{2,j}.(y_j^n(t) - x_{i,j}(t)) \quad (15)$$

$$r_{1,j} and\ r_{2,j} \in [0,1] \quad (16)$$

The position of particle x_i is updated using the developed equation 17

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (17)$$

This process is repeated to a specified number of trials is exceeded, or velocity updates are near to zero [16].

To optimize the control model, a PSO will be incorporated with the PI controller shown in Figure 11, both in the inner control and outer control in each side. The purpose of this method is to find the optimized gains of the PI

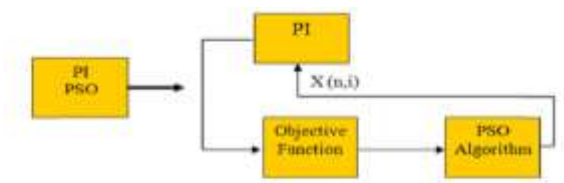

Fig 11 Insertion of PSO approach with the PI controller

Depending on the experience the initial data of the PI parameters are proposed on Table 1. The optimized value of this model can be obtained by the proposed technique.

TABLE 1 PARAMETERS OF PI GAINS

Type of controller	Outer control loop			Inner control loop	
		KP	KI	KP	KI
PSO-pi	VSC1	0.5	50	0.5	50
	VSC2	0.5	50	0.5	50
Traditional PI	VSC1	6	8	6	8
	VSC2	6	8	6	8

The system shown in Figure 1 with parameter shown in Table 2 is used to study some cases in the following part.

TABLE 2 THE SYSTEM PARAMETERS

Parameters	Value
Ac voltage U_{sr}, U_{si}	230 KV
ω_r, ω_i	2∗ pi ∗ 50 rad/s
Transformer ratio T_1, T_2	230KV/100KV
R_r, R_i	0.325Ω
L_r, L_i	0.072H
Rated voltage in DC side	±100KV
C	70μF
Unit resistance of DC line	1.39e-.002Ω
DC line length	75*2 KM

V. SYSTEM PERFORMANCE AND RESULTS DISCUSSION.

To study the performance of the system under study three cases will be applied and discussed in this part. The cases include the variation of active and reactive power with and without application of line to ground fault.

CASE 1: APPLICATION OF ACTIVE POWER.

At time = 0.5 sec the active power reference will increase from 0 to 1 PU where no reactive power. The obtained results are shown in Figure 12 which insure the PSO model gives efficient performances better than the PI traditional one.

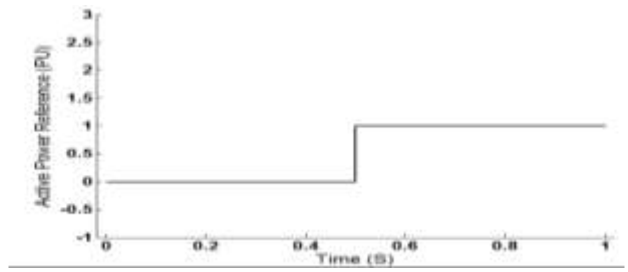

Fig 12a Active Power Reference

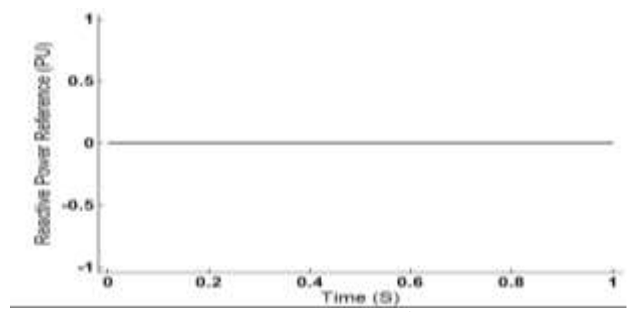

Fig 12b Reactive Power Reference

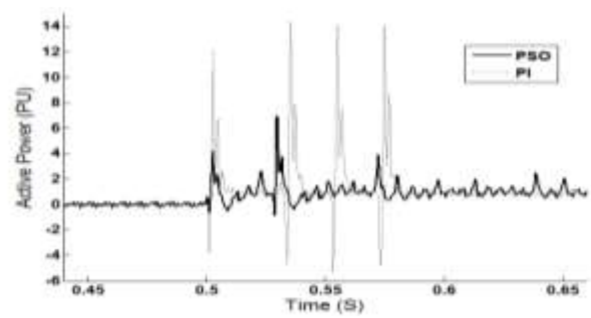

Fig 12c Active Power Variation

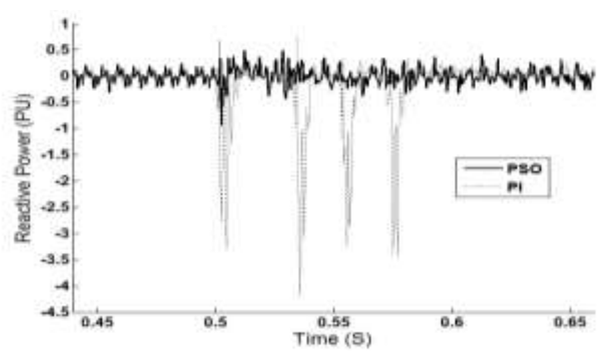

Fig 12d Reactive Power Variation

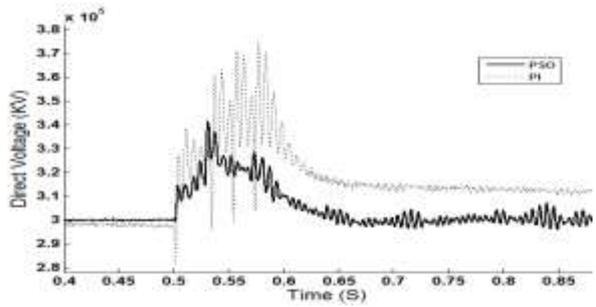

Fig 12e Direct Voltage Variation

CASE 2: APPLICATION OF REACTIVE POWER

At time = 0.5 sec the reactive power reference will increase from 0 to 1 PU where no active power. The results are shown in Figure 13. The proposed system insure the best performance and good stability.

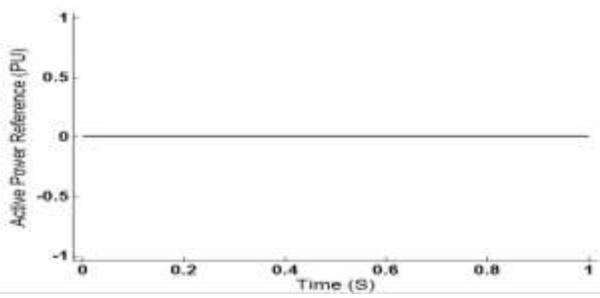

Fig 13a Active Power Reference

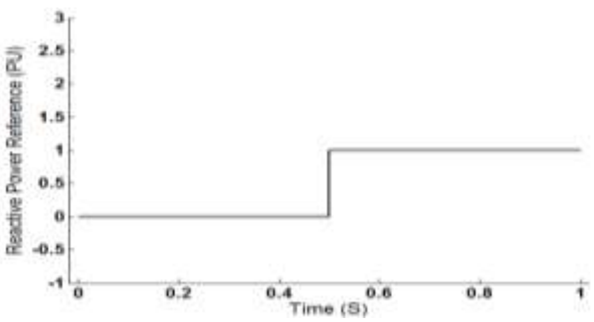

Fig 13b Reactive Power Reference

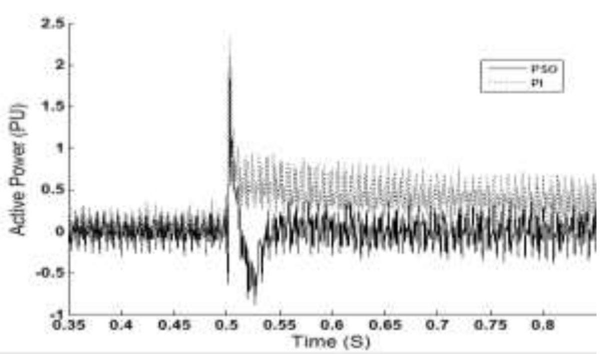

Fig 13c Active Power Variation

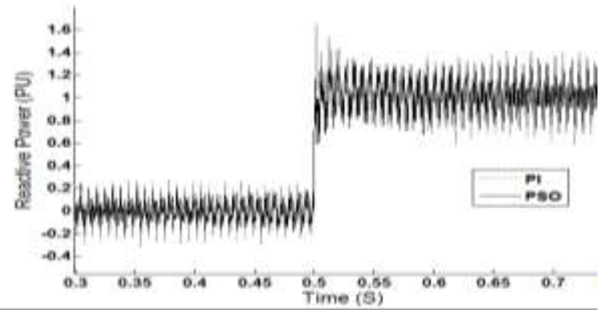

Fig 13d Reactive Power Variation

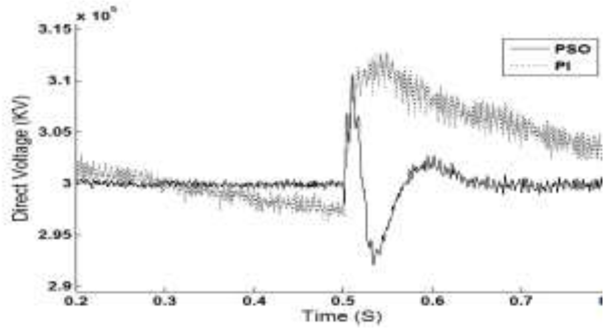

Fig 13e Direct Voltage Variation

CASE 3 THE PERFORMANCE UNDER LINE TO GROUND FAULT

To test the system performance at 0.5 sec, active power reference will be changed from 0 to 1 PU until one second then a line to ground fault is applied for a duration 0.2 sec and will be cleared at 1.2 sec. According to results (Figure14) the system introduces good and steady performance.

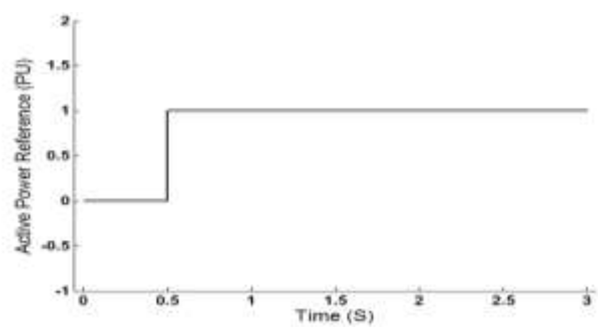

Fig 14a Active Power Reference

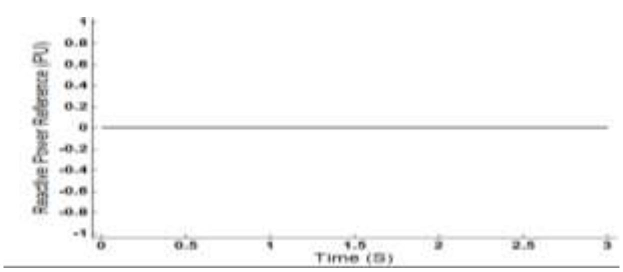

Fig14b Reactive Power Reference

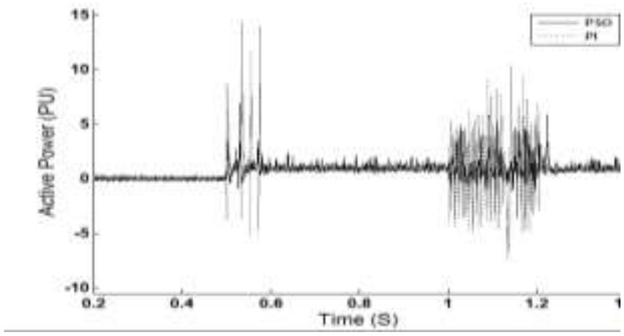

Fig 14c Active Power Variation

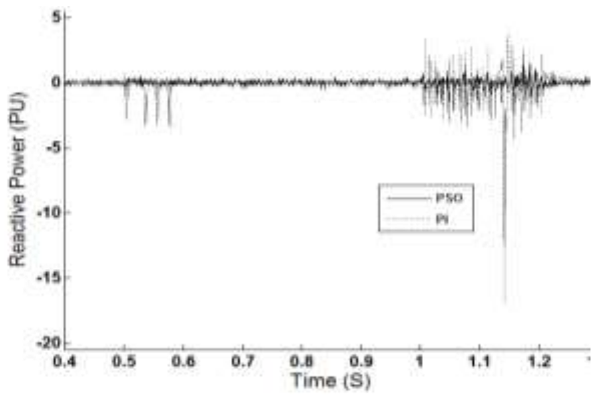

Fig 14d Reactive Power Variation

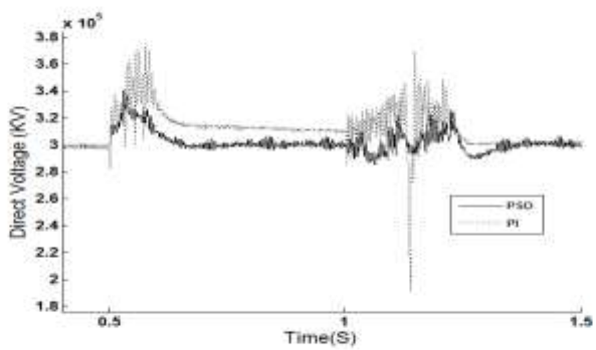

Fig 14e Direct Voltage Variation

VI. Conclusion

This paper presented a proposed method to optimize the parameters of PI controller of HVDC integrated in power system to solve some problems. Associated with the connection of different frequency regions. The proposed system could improve the system stability problem. The studied system was modelled by MATLAB SIMULINK. The initial parameters values were proposed depending on the author experience and compared with the obtained optimize ones. Three different cases were applied and discussed. They were the variation of active and reactive power with and without application of a line to ground fault. The obtained results insure that the designed system introduced high efficiency and better stability. The proposed methodology can be applied in any other systems with any case study.

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