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Stabilizing a Multi Machine Infinite Bus via Discrete PID Controller with PSS Excitation System

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ABSTRACT: The aim of this paper is to give improvement of a Conventional Proportional Integral Derivative (PID) with PSS system is replaced by Discrete PID controller with PSS of multi machine system which is presented for improving stability and obtained to well perform parameter from maximum sensitivity of multi machine system in SIMULINK environment. The rise of electricity demand in a power system and the widely spread of power control systems require the use of discrete-time devices. Discrete devices are widely spread and play an essential task in the operation and control of power system. The application of the discrete PID with PSS controller is investigated by means of simulation studies on multi machine infinite bus (MMIB) system. The functional blocks of discrete PID with PSS are developed in SIMULINK and simulation studies are carried out. A study case for the validation of the proposed SIMULINK mechanism is presented and analyzed with control application for a synchronous generator excitation system. The superior performance of this stabilizer in comparison to discrete PID with PSS of multi machine system proves the better efficiency than conventional PID with PSS controller. The comparison studies carried out for various results such as speed deviation, field voltage, rotor angle and load angle in simulations; this will be reachable steady state and dynamic response.

KEYWORDS: Power System Stabilizer, Automatic Voltage Regulator, Discrete PID Controller, Multi Machine infinite bus, Excitation System.

I. INTRODUCTION

In modern interconnected power systems all over the world, stability has become an important consideration. These considerable efforts have been placed on the application of excitation controller (power system stabilizer) to improve the dynamic performance of a synchronous generator under abnormal conditions, which in turn introduce low frequency oscillations affecting the maximum power transfer capability limits. Low frequency oscillations are generator rotor angle oscillations having a frequency between 0.1-3.0 Hz and are defined by how they are created or where they are located in the power system.

All the PID with Power system stabilizer mentioned are fixed Gain Controllers of which the gain settings are determined based on a particular operating condition. In order to have the best controller gains over a wide range of loading conditions and to achieve better dynamic performance when the generator is subjected to large disturbance, a discrete PID with PSS controller gains may be employed. The oscillations, which are typically in the frequency range of 0.1 to 3.0 Hz. might be excited by disturbances in the system or, in some cases, might even build up spontaneously. These oscillations limit the power transmission capability of a network and, sometimes, may even cause loss of synchronism and an eventual breakdown of the entire system. In practice, in addition to stability, the system is required to be well damped (oscillations), when excited, should die down within a reasonable amount of time. Reduction in power transfer levels and AVR gains does curb the oscillations and is often resorted to during system emergencies. These are however not feasible solutions to the problem. The stability of the system, in principle, can be enhanced substantially by application of some form of close-loop feedback control. Over the years a considerable amount of effort has been extended in laboratory research and on-site studies for designing such controllers. The stability of the system can be improved, by using discrete PID controller with PSS in multi machine infinite bus.

The problem, when first encountered, was solved by fitting the generators with a feedback controller which sensed the rotor slip or change in terminal power of the generator and fed it back at the AVR reference input with proper phase lead and magnitude so as to generate an additional damping torque on the rotor. This device came to be known as a Power System Stabilizer (PSS). A PSS prepares with discrete PID controller signals as an input in phase with the synchronous rotor speed deviation to excitation systems resulting in generator stability. The principles of operation of this controller are based on the concepts of damping and synchronizing torques within the generator. These controllers have been known to work quite well in the field and are extremely simple to implement. This paper deals with discrete PID with stabilizer to damp out the oscillations with required design requirements. When the stabilizers are correctly with discrete PID the resulting damping action will be robust. The main advantages of these are a cost effective and fast response compared to the conventional PID controller when used for damping application.

II. DISCRETE PID WITH PSS EXCITATION SYSTEM

The discrete PID with PSS excitation system modeling of synchronous generator in fig.1 prefer is the mechanical power reference, P_{SV}, is the feedback through the governor T_m, is the turbine output torque V_{inf} is the infinite bus voltage, V_{ref} is the terminal voltage reference, V_t is the terminal voltage, V_a is the voltage regulation output. ω is the speed deviation. V_{PSS} is the discrete PID with PSS output, V_f is field voltage. V_t is excitation system stabilizing signal. P is the active and Q is the reactive power and the terminal power. The speed of the synchronous generator is governed by speed governor. The output of the rotor speed deviation governor is compared with reference power and given to turbine which is connected to the synchronous generator. The rotor speed deviation of synchronous generator is given to discrete PID with PSS as input whose output is used to get the stable voltage (V_{PSS}). The stable voltage is given to synchronous generator through the voltage regulator and exciter.

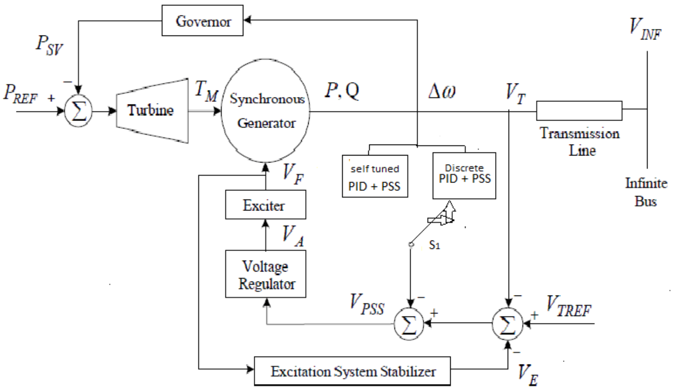

Fig.1: Excitation System Model Configuration

The output of voltage of the exciter is given to excitation system stabilizer and compared with reference terminal voltage. The output power from the synchronous generator is given to infinite bus through transmission voltage. To discrete PID with PSS will be doing no more work if the switch S_1 is changed to zero position. Then the system will stabilized more than conventional PID with PSS excitation system.

A. Exciter and Automatic Voltage Regulator

Interconnected power systems cannot operate without control, Manual and automatic controls have to be implemented (e.g. Automatic Voltage Regulators, Speed Governors and Power system stabilizers). These controls ensure that systems operate in unison at maximum efficiency. High performance excitation systems are essential for maintaining the small signal stability of modern synchronous generators. They are characterized by high initial response and increased reliability due to advances in discrete PID with PSS in excitation system. Introduced controller type is used for voltage control and generator stabilization. The main advantage is that there are cost effective and more sensitivity.

The discrete PID controller has two control loops: voltage control loop and damping control loop, and in that way unifies Automatic voltage controller and PSS. Simulation and experiment indicated that, compared to conventional PID with PSS excitation system and discrete PID with PSS excitation controller and shows improved static as well as dynamic operating conditions.

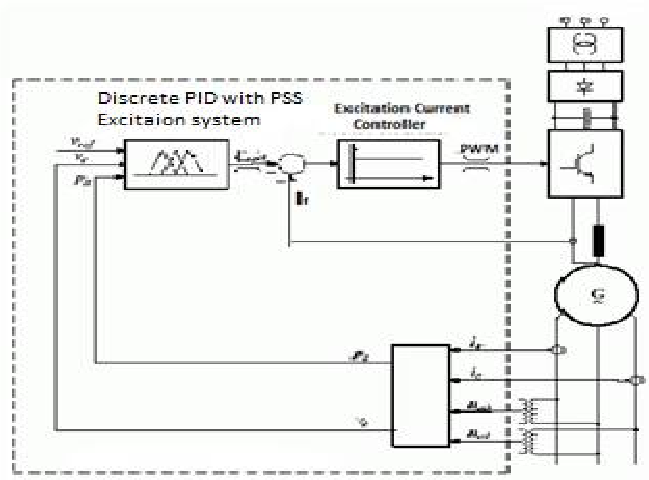

Fig. 2: Discrete PID with PSS Excitation System

The block diagram shown in fig.3 of a typical excitation system shown in Figure, A low pass filter time constant sT_A can be set in the range of 0.01 to 0.02 sec which is necessary for filtering of the rectified terminal voltage waveform. The Automatic voltage regulator gain is typically around 250 p.u. The exciter ceiling is typically 8.0 p.u. These parameters permit the exciter to reach 90% of the rated load field voltage within 2 ms for a sustained drop in the terminal voltage not exceeding 5%. If the gain of AVR is too high it can contribute to oscillatory instability in power systems which can endanger system security and limit power transfer.

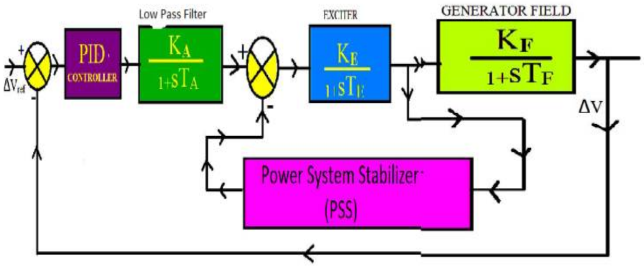

Fig. 3: Block Diagram of Discrete PID with PSS Excitation system

Block Parameters of Excitation system as follows:

i. **Low-pass filter time constant:**

The time constant $\mathbf{T}_{A,}$ in seconds (s), of the higher-order system that represents the stator terminal voltage transducer.

ii. **Regulator gain and time constant:**

The gain $\mathbf{K}_a$ and time constant T_a, in seconds (s), of the higher-order system representing the main regulator.

iii. **Exciter:**

The gain $\mathbf{K}_e$ and time constant T_e, in seconds (s), of the higher-order system representing the exciter.

iv. **Transient gain reduction:**

The time constants $\mathbf{T}_b$, in seconds (s) and $\mathbf{T}_c$, in seconds (s), of the discrete system representing a lead-lag compensator.

v. **Generator field gain and time constant:**

The gain $\mathbf{K}_f$ and time constant $\mathbf{T}_f$, in seconds (s), of the discrete system representing a derivative feedback.

vi. **Regulator output limits and gain:**

Limits $\mathbf{E}_{f\ (min)}$ and $\mathbf{E}_{f\ (max)}$ are imposed on the output of the voltage regulator. The upper limit can be constant and equal to $\mathbf{E}_{f\ (max)}$ or variable and equal to the rectified stator terminal voltage $\mathbf{V}_{tf}$ times a proportional gain $\mathbf{K}_p$. If $\mathbf{K}_p$ is set to zero, the former applies. If $\mathbf{K}_p$ is set to a positive value, the latter applies.

vii. **Initial values of terminal voltage and field voltage:**

The initial values of terminal voltage $\mathbf{V}_{t0}$ (p.u.) and field voltage $\mathbf{V}_{f0}$ (p.u.). When set correctly, they allow you to start the simulation in steady state. Initial terminal voltage should normally be set to 1 p.u. Both $\mathbf{V}_{t0}$ and $\mathbf{V}_{f0}$ values are automatically updated by the load flow utility of the Power GUI block.

B. Power System Stabilizer

A solution to the problem of oscillatory instability is to provide damping for the generator oscillations by providing Power System Stabilizers (PSS) which are supplementary controllers in the excitation systems. The signal V_{PSS} is the output from PSS which has input derived from rotor velocity, frequency, electrical power or a combination of these variables.

Structure and optimization of PSS:

The Power System Stabilizer (PSS) block can be used to add damping to the rotor oscillations of the synchronous machine by controlling its excitation. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system stability. The output signal of the PSS is used as an additional input ($\mathbf{V}_{stab}$) to the Excitation System block. The PSS input signal can be either the machine speed deviation $\boldsymbol{\omega}$, or its acceleration power, $\mathbf{P}_a = \mathbf{P}_m - \mathbf{P}_{oe}$ (difference between the mechanical power and the electrical power). The Power System Stabilizer is modeled by the following nonlinear system:

To ensure a robust damping, the PSS should provide a moderate phase advance at frequencies of interest in order to compensate for the inherent lag between the field excitation and the electrical torque induced by the PSS action. The model consists of a low-pass filter, a general gain, a washout high-pass filter, a phase-compensation system, and an output limiter.

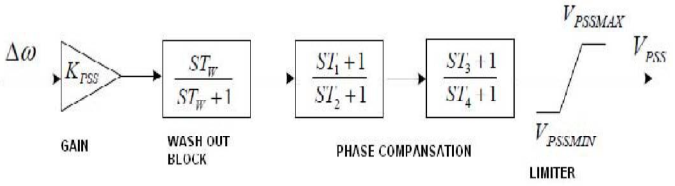

Fig.4: Conventional Power System Stabilizer

i. Gain:

The overall gain **K** of the generic power system stabilizer. The gain K determines the amount of damping produced by the stabilizer. Gain **K** can be chosen in the range of 20 to 200.

ii. Wash-out time constant:

The time constant, in seconds (s), of the first-order high pass filter used by the washout system of the model. The washout high-pass filter eliminates low frequencies that are present in the speed deviation signal and allows the PSS to respond only to speed changes. The Time constant $\mathbf{T}_w$ can be chosen in the range of 1 to 2 for local modes of oscillation. However, if inter area modes are also to be damped then $\mathbf{T}_w$ must be chosen in the range of 10 to 20.

iii. Lead-lag time constants:

The numerator time constant $\mathbf{T}_{1n}$, $\mathbf{T}_{2n}$ and denominator time constant $\mathbf{T}_{1d}$, $\mathbf{T}_{2d}$ in seconds (s), of the first and second lead-lag transfer function. The phase-compensation system is represented by a cascade of two first-order lead-lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

iv. Limiter:

The output of the PSS must be limited to prevent the PSS acting to counter the action of AVR. The negative limit of the PSS output is of importance during the back swing of the rotor (after initial acceleration is over). The AVR action is required to maintain the voltage after the angular separation has increased. PSS action in the negative direction must be shortened more than in the positive direction. A typical value for the lower limit is -0.05 and for the higher limit it can vary between 0.1 to 0.2.

C. Discrete PID Controller

The discrete-time closed-loop PID controller is the most popular controller. It is faster time response and rise time than the continuous-time PID controller. Although, we have to check the stability in a continuous-time of any digital controller, but after using z-transform to convert the system to a digital control system we use the digital signals as an input to the computer.

The main structure of a digital control system:

To control a physical system or process using a digital controller, the controller must receive measurements from the system, process them, and then send control signals to the actuator that effects the control action. In almost all applications, both the plant and the actuator are analog systems. This is a situation where the controller and the controlled do not “speak the same language” and some form of translation is required. The translation from controller language (digital) to physical process language (analog) is performed by a digital-to-analog converter, or DAC. The translation from process language to digital controller language is performed by an analog-to-digital converter, or ADC. A sensor is needed to monitor the controlled variable for feedback control. The combination of the elements discussed here in a control loop is shown in fig.5 Variations on this control configuration is possible.

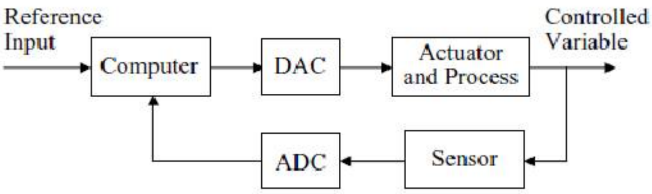

Fig.5 main structure of digital control system.

Z-transform used as a key for discrete-time systems to solve the difference equations to show the output response of the control systems. Suppose f(t) is a continuous function and we sample this function at time intervals of T, thus obtaining the data;

$$f(0), f(T), f(2T), \ldots.., F(nT), \ldots\ldots$$

let,

$$z = e^{st} \text{ or equivalently } s = 1/T * \log(Z)$$

Thus;

$$F(z) = \sum_{n=0}^{\infty} f(nT)z - 1$$

$$G_{ZOH}(s) = 1\text{-}e^{-st}/s$$

To convert the equation to a z-transform:

$$G_{ZOH}(Z) = (1\text{-}Z^{-1})\, \mathcal{Z}\,(1/s)$$

Design discrete-time PID controller:

Digital compensators designed in the z domain for discrete-time control system.

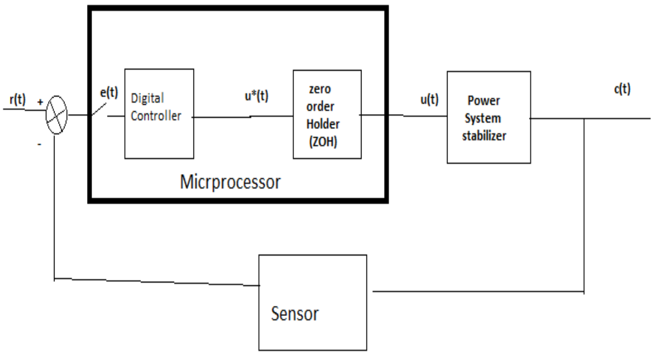

Fig.6 General Form of a Digital Controller

Fig.6 shows the general form of digital control system. The pulse transfer function of the digital controller/compensator is written:

$$U(z)/E(z) = D(z) \qquad (1)$$

The closed-loop transfer function of the system becomes:

$$C(z)/R(z) = D(z)\ G(z)/1+D(z)\ G\ H(z) \qquad (2)$$

The characteristic equation is :

$$1+D(z)\ G\ H(z) = 0 \qquad (3)$$

In a continuous system, a differentiation of the error signal e(t) can be represented as :

$$U(t) = d(e)/dt \qquad (4)$$

By taking the Laplace transform with zero initial conditions :

$$U(s)/E(s) = s \qquad (5)$$

In discrete-time control system, a differentiation can be approximated to :

$$u(kt) = e(kt) – e(k\text{-}1)T/\ T \qquad (6)$$

The z-transform will be:

$$U(z)\ /\ E(z) = 1\text{-}Z^{-1}/T \qquad (7)$$

Hence, the Laplace operator can be approximated to :

$$S = 1\text{-}Z^{-1}/T = z\text{-}1/\ Tz \qquad (8)$$

Digital PID controller from the above equation:

$$\mathbf{U(z)} = \frac{\mathbf{Kp\ \{\ Ti\ Td\ (1 – Z/\ Tz)2 + Ti\ (1 – Z/\ Tz)2 + 1\}}}{\mathbf{Ti\ (1 – Z/\ Tz)2}} * \boldsymbol{E(z)} \quad \mathbf{(9)}$$

This equation shows the response of discrete PID which has lot of benefits when we use digital PID controllers instead of using continuous PID controller they could summarize in following points:

1. **Accuracy.** Digital signals are represented in terms of zeros and ones to represent a single number. This involves a very small error as compared to analog signals where noise and power supply drift are always present.
2. **Implementation errors.** The errors that result from digital representation and arithmetic are negligible. By contrast, the processing of analog signals is performed using components such as resistors and capacitors with actual values that vary significantly from the nominal design values.
3. **Flexibility.** An analog controller is difficult to modify or redesign once implemented in hardware. A digital controller is implemented in firmware or software, and its modification is possible without a complete replacement of the original controller.
4. **Speed.** The speed of computer hardware has increased exponentially. This increase in processing speed has made it possible to sample and process control signals at very high speeds.
5. **Cost.** Although the prices of most goods and services have steadily increased, the cost of digital circuitry continues to decrease.

III. DESIGN OF DISCRETE PID WITH POWER SYSTEM STABILIZER FOR MULTI MACHINE INFINITE BUS

Due to the difficulties in data transmissions among individual generators that are located at geographically dispersed area, it is a common practice to use decentralized control schemes in the design of discrete PID with power system stabilizers for multi machine infinite bus system.

The basic principles underlying the design of the proposed discrete PID power system stabilizer can be illustrated by the block diagram in fig.7, in which a synchronous generator with a static exciter is equipped with a discrete PID with PSS whose gain settings K_P, T_i and T_d are adjusted according to the adaptation law described below with the on-line measured generator speed deviation $\Delta\omega_i$ as the input signal to adaptive stabilizer.

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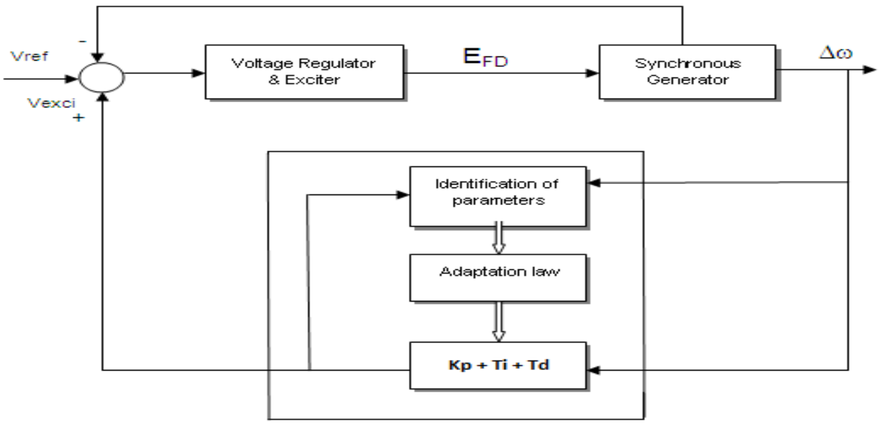

Fig. 7: Discrete PID with PSS

In the present study, the main purpose of the PSS is to enhance the damping of the low frequency electromechanical oscillation characterizing generator rotor dynamic behavior which can be described by a second order equation. Therefore, second order polynomials will be sufficient for $A(q^{-1})$, $B(q^{-1})$:

$$A(q^{-1}) = 1 + a_1 q^{-1} + a_2 q^{-2} \qquad (10)$$

$$B(q^{-1}) = b_1 q^{-1} + b_2 q^{-2} \qquad (11)$$

In otherworld, the input-output relationship can be described by a second order difference equation:

$$y(k) + a_1 y(k-1) + a_2 y(k-2) = b_1 u(k-1) + b_2 u(k-2) \qquad (12)$$

By continuously measuring the input samples u(k) and output samples y(k), the four coefficients a_1, a_2, b_1 and b_2 can be estimated in real time by using recursive least squares identification method.

With a_1, a_2, b_1 and b_2 estimated using RLS identifier, the four parameters $r_1.S_0$, S_1 and S_2 may be obtained by solving the below equations.

$$r_1 + b_1 S_0 = 1 - a_1 + \alpha + a_1\alpha \qquad (13)$$

$$r_1 (a_1 - 1) + b_1 S_1 + b_2 S_0 = a_1 - a_2 + a_1\alpha^2 + a_2\alpha^3 \qquad (14)$$

$$r_1 (a_2 - a_1) + b_2 S_1 + b_1 S_2 = a_2 + a_2\alpha^3 \qquad (15)$$

$$-a_2 r_1 + b_2 S_2 = 0 \qquad (16)$$

With r_1, S_0, S_1 and S_2 the discrete PID gains can be obtained using below expressions.

$$Kp = (S_1 + 2S_2) / (1 + r_1) \qquad (17)$$

$$Ti = -(S_0 + S_1 + S_2) / T_S \qquad (18)$$

$$Td = \{[r_1 S_1 - (1 - r_1) S_2] / (1 + r_1)\} T_S \qquad (19)$$

These gain settings are computed at each sampling instant using the present estimated values of the four coefficients a_1, a_2, b_1 and b_2, characterizing generator dynamic behavior at that instant.

IV. MODELLING OF DISCRETE PID WITH PSS FOR MULTI MACHINE INFINITE BUS USING SIMULINK

To analysis the performance of the discrete PID with PSS, Simulation model was developed in Simulink block set of MATLAB. The functional block set of discrete PID with PSS in Simulink environment shown in fig. 8 the effectiveness of discrete PID with PSS is investigated for various operating conditions using the Simulink model. Independent of the technique utilized in tuning stabilizer equipment, it is necessary to recognize the nonlinear nature of power systems and that the objective of adding power system stabilizers along with discrete PID controller is to extend power transfer limits by stabilizing system oscillations; adding damping is not an end in itself, but a means to extending power transfer limits. The various blocks involved in modeling the synchronous machine are:

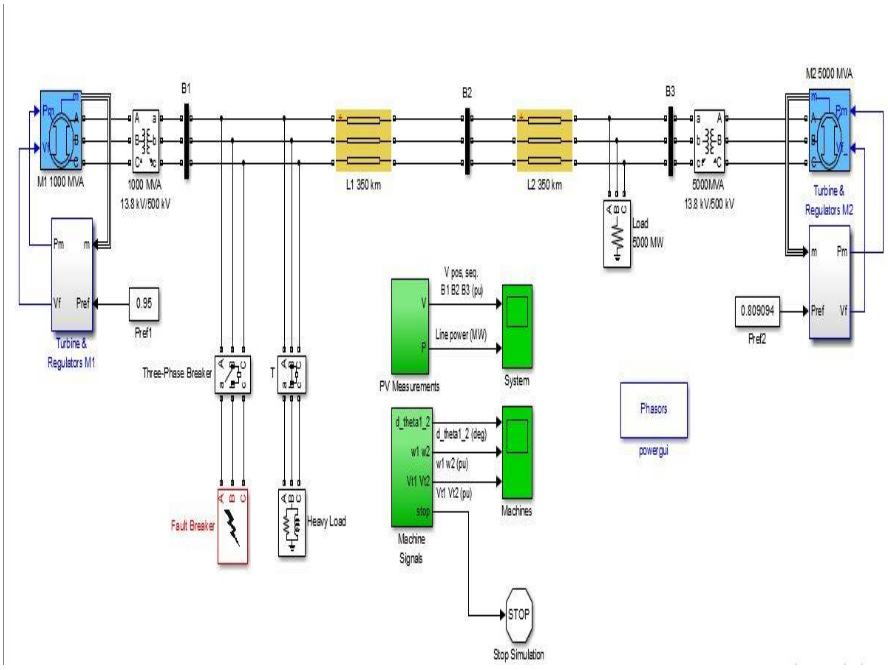

Fig.6: MATLAB Simulink of Discrete PID with PSS for Multi Machine Infinite Bus

V. SIMULATION RESULTS AND DISCUSSION

The performances of conventional PID with PSS for single machine infinite bus and PSS with discrete PID for multi machine infinite bus are studied in the Simulink environment for different operating conditions and the following test cases was considered for simulations.

Case i: For normal load without fault and heavy load condition, the variation of speed deviation, field voltage, rotor angle and load angle were analyzed for discrete PID with PSS.

Case ii: System was subjected to vulnerable (fault) condition, the variation of above mentioned cases were analyzed.

Case iii: The variation of above mentioned cases were analyzed for PSSs when subjected to heavy loading condition.

The above cases are illustrated clearly, how the controller reduces the overshoot and settling time to the nominal level when subjected to discrete PID with PSS and the inference of the simulation results are as follows.

Case I: Normal load without fault and heavy load.

Here, the synchronous machine subjected to normal load of 1000MW without fault condition in the transmission line and the following observations from the dynamic responses are made in Fig.7 (a-b-c) to Fig. 8 (a-b) with respect to the stability of the system.

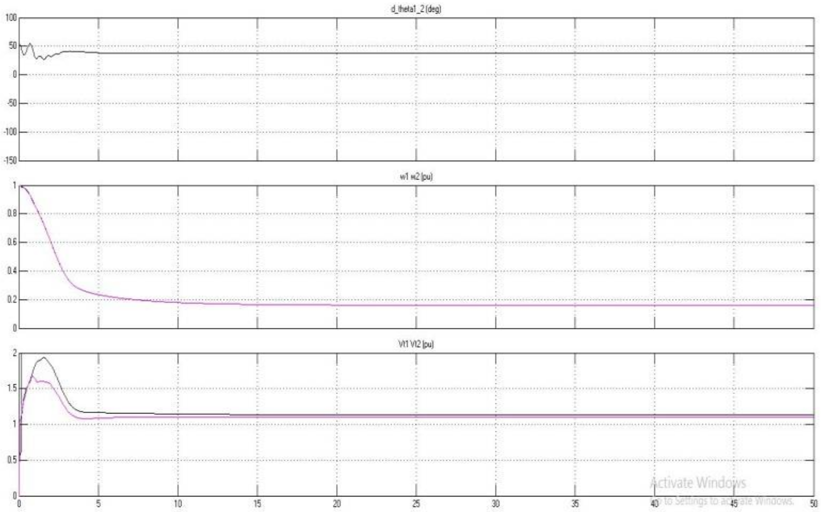

Fig. 7 (a) Rotor angle deviation in degree under normal load
(b) Rotor speed deviation p.u. under normal load
(c) Terminal Voltage in p.u. under load

From the Fig.7 (a) rotor angle deviation, it is observed that the discrete PID with PSS can provide the better damping characteristic than the other cases. The discrete PID with PSS reduced the overshoot to 7-10 degree and the system reaches the steady state quickly compared to PSS. By this effect, the field voltage will be stable and in turn it ensures the system stability. In the response of Speed deviation Fig.7 (b), the overshoot reduced to 0.6 from 0.8 p.u. using discrete PID with PSS therefore the system reaches the stable state quickly. It is necessary to maintain the speed in the synchronous generator; care should be taken to make the system to reach steady state as early as possible for that discrete PID with PSS give better optimal solution compared to others.

Fig.7 (c). , the terminal voltage reaches the stable state at 0.8 to 1 p.u. Here also inferred that after the inclusion discrete PID with PSS the damping oscillation was reduced and also it boosts up to 2 p.u. to 1.2 p.u. According to Fig.8 (a-b), discrete PID with PSS improves the field voltage and line power to the maximum extent by reaching the settling time before 1.5 secs. However the field voltage and line power are optimized, the discrete PID with PSS improves the performance compared to other PSS technology.

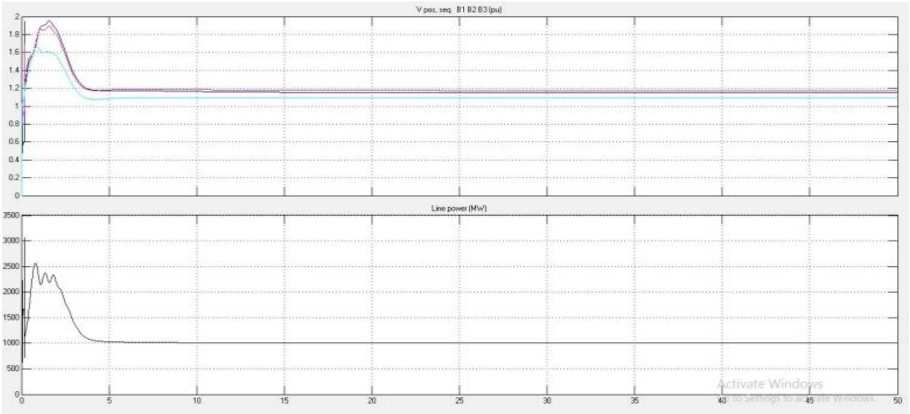

Fig. 8: (a) Field Voltage in p.u. under normal condition
(b) Line Power in MW under normal condition

Case II: Fault Condition:

This illustrates the stability of the system during vulnerable condition, a three phase fault is assumed to happen at the transmission line. The fault persists in the system after 12 sec and it is cleared after 0.1 sec i.e. 12.1 sec. The parameters of the system during fault condition are illustrated in Fig. 9 (a-b-c) to Fig. 10 (a-b).

From the Fig. 9 (a), the overshoot was high for PSS; therefore the stability of the system was affected. The discrete PID with PSS reduces the overshoot to 50% and makes the system to reach steady state before 2 secs. From this case, it is inferred that PID with PSS supports the synchronous generator to maintain synchronous speed even at severe fault conditions. During the fault condition, PSSs maintains the load angle around zero degree.

Normally for the smart system the load angle should be maintained around 15 to 45 degree. The PID with PSS provides better solution by maintaining the load angle around 10-15 degree.

From the Fig. 9 (b), it is observed that the PSS produced more overshoot and settles at 5 secs about speed deviation of system under fault condition. The discrete PID with PSS controller gives better solution compared to normal PSS. The combination of PID with PSS further reduces the settling time to 0.2 secs and also the overshoot. Last one the Fig. 9 (c), it is inferred that the accelerate stabilization of terminal voltage in p.u. with respect to Fault condition. However with the help of PID with PSS, the rotor angle maintained at normal level compared to PSS.

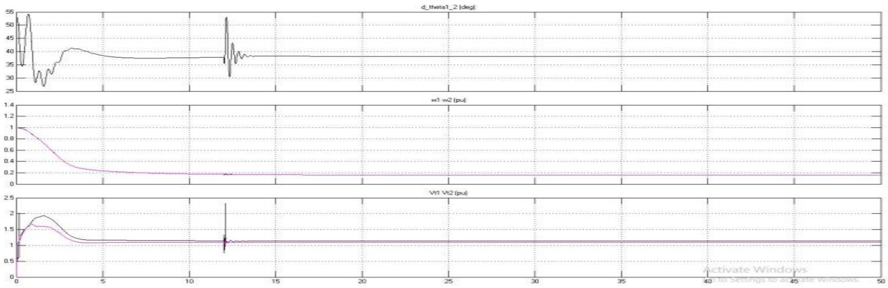

Fig. 9: (a) Rotor angle deviation in degree under fault condition
(b) Rotor speed deviation p.u. under fault condition
(c) Terminal Voltage in p.u. under fault condition

According to Fig.10 (a-b), discrete PID with PSS improves the field voltage and line power to the maximum extent by reaching the settling time before 0.1-0.2 secs. However the field voltage and line power are optimized, the discrete PID with PSS improves the performance compared to other PSS techniques.

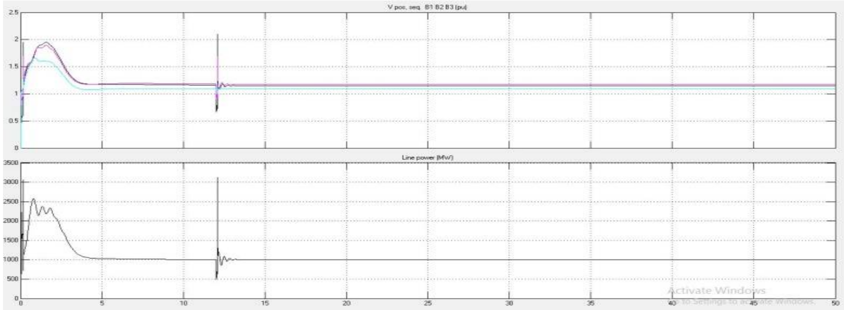

Fig. 10: (a) Field Voltage in p.u. under fault condition
(b) Line Power in MW under fault condition

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Case III: Heavy Load:

In this case, the Synchronous generator is subjected to three phase R-L load of 5000MW in the transmission line. The performance characteristics of the system with discrete PID with PSS are illustrated from Fig. 11(a-b-c) to Fig. 12 (a-b).

From the Fig. 11, (a) the discrete PID with PSS provides better solution by reducing overshoot to 75% and the settling time around 0.2 secs even in heavy load condition. By this effect the rotor angle deviation will be stable and in turns maintain the system stability. According to Fig.11 (b), the overshoot was heavy for PSS, in turn affects the stability of the system. The discrete PID with PSS reduces the overshoot to 50% and makes the system to reach steady state before 0.2 secs. Therefore it is inferred that discrete PID with PSS supports the synchronous generator to maintain synchronous rotor speed even at severe fault conditions but with some negative damping. During the load condition, the discrete PID with PSS makes the system to settle at 0.1 – 0.2 secs. Also it boosts up the system to maintain terminal voltage in and around 0.8 to 1 p.u. In this case also the proposed system maintains stability.

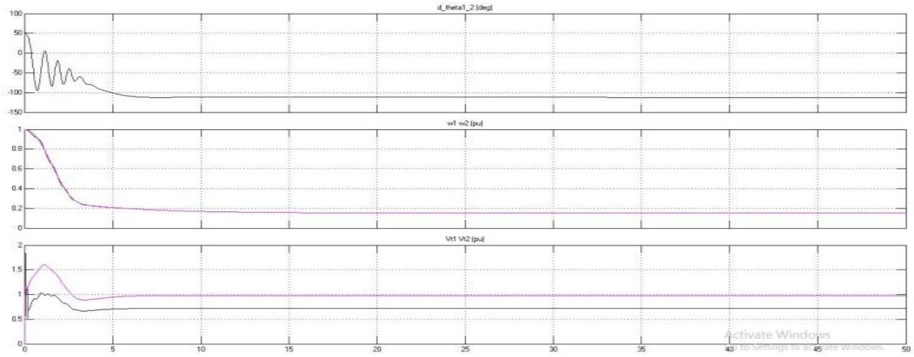

Fig. 11: (a) Rotor angle deviation in degree under heavy load condition
(b) Rotor speed deviation p.u. under heavy load condition
(c) Terminal Voltage in p.u. under heavy load condition

From the Fig. 12 (a-b), it is inferred that the discrete PID with PSS maintains the stability with small amount of damping compared to other techniques of PSS. The Discrete PID with PSS reduces the overshoot to 25% and the system settles at 0.1-0.2 secs.

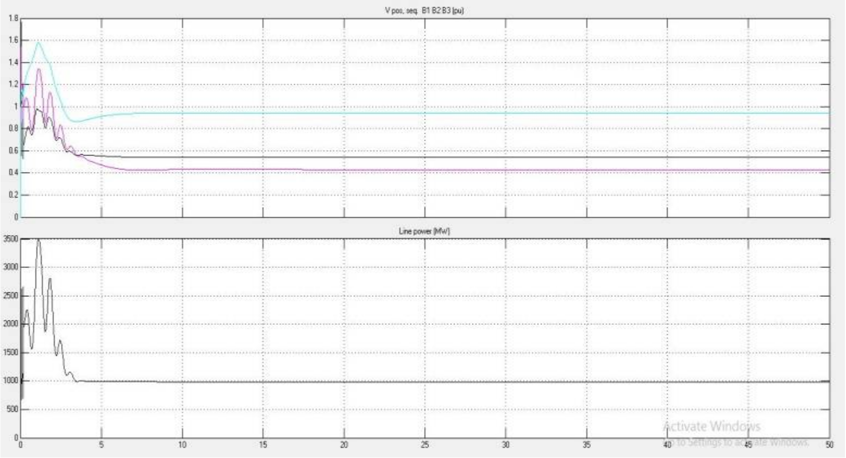

Fig. 10: (a) Field Voltage in p.u. under heavy load condition
(b) Line Power in MW under heavy load condition

Finally the above three cases are summarized by the Following points:

- The discrete PID+PSS can provide better damping characteristic than the PID, PSS even at the loading condition. This results from the fact that, during the faulted period, there will be drastic change in the operating condition.
- As evidenced by the curves mentioned above , the transient stability limit of the synchronous machine can be improved by the discrete PID+PSS since the generator with PSS and PID will have more overshoot and settling time when the load is increased to 5000MW, while the one with discrete PID+PSS will still remain stable.
- The damping characteristic of the discrete PID+PSS is insensitive to load change while that of PSS and PID controller will deteriorate as the load changes.
- The discrete PID+PSS can offer better responses in field voltage as well as angular speed. Therefore, the major disadvantage of being liable to cause too great deviation in the voltage profile when an excitation controller is employed to improve the damping can be avoided.
- Therefore the proposed discrete PID+PSS is relatively simpler than the other controllers for practical implementation and also produces better optimal solution.

VI. CONCLUSION

Results from this study indicate that under large disturbance conditions, better dynamic responses can be achieved by using the proposed discrete PID with PSS controller than the other stabilizers. We could also observe in all case studies, from the MATLAB/ Simulink simulation, that the discrete PID with PSS controller has an excellent response with small oscillations, while the other controller response shows a ripple in all case studies and some oscillations before reaching the steady state operating point. It was shown that an excellent performance of the discrete PID with PSS control in contrast to the other controllers for the excitation control of synchronous machines could be achieved. Modeling of proposed controller in Simulink environment shown the accurate result when compared to mathematical design approach. A simple structure of a discrete PID controller and its wide spread use in the industry make the proposed stabilizer very attractive in stability enhancements.

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