

Performance Enhancement of Automatic Voltage Regulator (AVR) For Stability in Power Generation

ATUCHUKWU, A.J.¹, UJU, I.U.², AWGU, IFEANYI MADUABUCHI³

^{1, 2, 3} Department of Electrical and Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Nigeria

Abstract- This paper proposed enhanced Automatic Voltage Regulator (AVR) Stability in Nigeria power station. The techniques were based on utilizing Simulink in building system models and simulating their behaviors. Data on voltage stability analysis were collected from Kainji Hydropower plant in Nigeria and simulated to evaluate the control response in both time-domain and frequency-domain. Later, the enhanced automatic voltage regulator for stability was deployed. Result obtained showed that application of enhanced automatic voltage regulator for stability was reliable and effective. For stability enhancement, the terminal output voltage generated settled about 5 seconds with disturbances and tends to stabilize approximately at desired value. Without stability enhancement, the response was oscillating with large overshoot and no settling time. The simulation results showed that this method can effectively estimate the transient stability with significant simplicity and generality, which was practically useful to secure the operation and control for power electronics dominated power systems. Automatic Voltage Regulator (AVR) for stability in power generation was also enhanced by introducing a compensator known as a PID circuit in which the error is amplified proportionately (P), integrated (I) and differentiated (D). The three design parameters of this controller; proportional gain K_p , integral gain K_i and derivative gain K_d , must be tuned jointly by the operator depending upon the plant's design parameters. The resulting response against a unit step input should correspond with the given reference with minimal settling time and no sustained oscillation.

I. INTRODUCTION

In elementary generation, an electrical generator is a device that converts mechanical energy to electrical energy generally; using electromagnetic induction, the reverse conversion of electrical energy into mechanical energy is done by a motor. Motors and generators have many similarities. A generator forces electric charges to move through an external electric circuit but it does not create electricity or charge which is already present in the wire of its windings. The source of mechanical energy may be a reciprocating or turbine steam engine, water falling into a turbine or water wheel, an internal combustion engine or wind turbine, or hard crank, or compressed air or any other source of mechanical energy can be used.

- Kainji Hydropower Station Stability Analysis Data Sample

Table1.1 Summary of disturbance events

DISTURBANCE EVENT	DAT E	FREQUE NCY CHANGE	MW CHANG E	β (MW/0.1 Hz)
1. Generation Increase	06/12/2020	+ 55 MHz	+ 118-141 MW*	21.6-25.65
2. Loss of Generation	06/12/2020	- 46 MHz	- 100 MW	21.74
3. Loss of Kainji Hydro Power Station	12/02/2020	- 32 MHz	- 7h0 MW	21.65

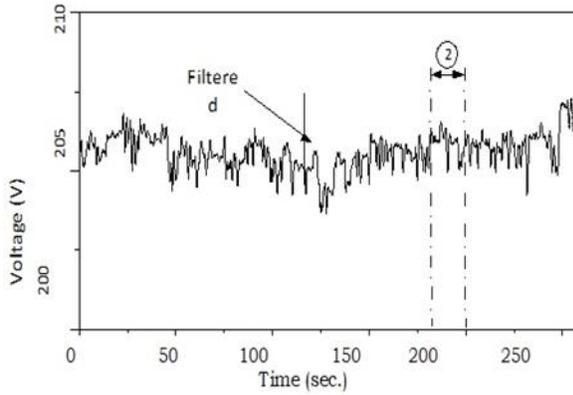


Figure 1.1 Filter FDR voltage

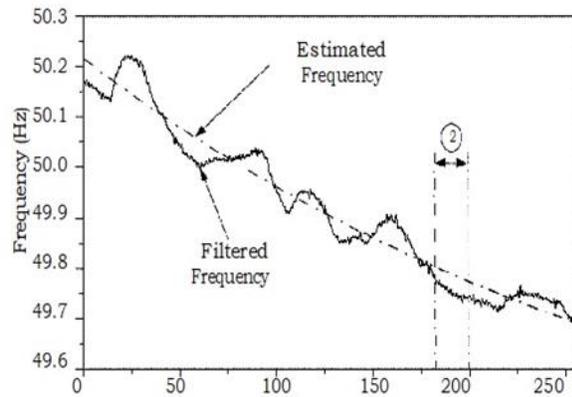


Figure 1.2 Filter FDR frequencies

2.0 Mechanical Model of Synchronous Generator

The torque developed by the machine when generating is negative mechanical. The externally -applied mechanical torque in the direction of rotation, will be negative when the machine is motoring a load and will be positive when the rotor is been driven by a prime mover as in generating. If the frictional torque acts in a direction opposite to the rotor’s rotation,

Equating the net acceleration torque to the internal, we have;

$$T_{em} + T_{mech} - T_{damp} = J \frac{d\omega_{rm}(t)}{dt} = \frac{2J}{P} \frac{dW_r(t)}{dt} \text{ Nm} \quad (1.1)$$

The rotor angle δ is define as the qr-axis of the rotor with respect to q axis is of the synchronously rotating reference frame that is

$$\delta(t) = Y_r(t) - Y_e(t) \text{ elect rad} \quad (1.2)$$

$$\int_0^t [w_r(t) - w_e] dt + Y_r(\delta) - Y_e(0) = \quad (1.3)$$

Since W_e is constant

$$\frac{\delta[w_r(t) - w_e]}{\delta} = \frac{\delta w_r(D)}{dt} \quad (1.4)$$

Using the equation (1.3) to replace $\frac{\delta w_r(t)}{dt}$ into equation (1.4) the slip speed can be determined from an integration of

$$w_r(t) - w_e = \frac{1}{2J} \int_0^t (em + T_{mech} - T_{dam}) dt \text{ at } e \text{ ect}^{rad} \quad (1.5)$$

2J

And

$$T_{em} = (3/2) (P/2W) [(-X_d l_d + X_{md} l_{ka} + X_{md} l_{fa}) l_q - (X_q l_q + X_{mq} l_{ka}) l_d]$$

Analyzing the steady state frequency responses for automatic generation control (AGC) in a single area system, with the primary load feedback control (LFC) loop, a change in the system load will result in a steady-state frequency deviation, depending on the governor speed regulation.

In order to reduce the frequency deviation to zero, the rest action can be achieved by introducing an integral controller to act on the load reference setting to change the speed set point The integral controller increases the system type by one (1) which forces the final frequency deviation to zero. The simple model of the LFC with the addition of the secondary loop is shown in figure 1.3. The integral controller gain, k_i , must be adjusted for a satisfactory transient Response

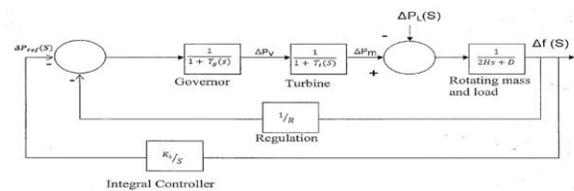


Figure 1.3 AGC for Isolated Power System.

Where ΔP_v = change in Electrical equivalent power (governor).

ΔP_m = change in mechanical equivalent power (turbine).

$\Delta P_L(s)$ Output integral (Load).

The closed - loop transfer function of the control system shown above with only PL Output integral

(load) as input becomes.

$$\frac{\Delta f}{\Delta PL} = \frac{S(1+TgS)(1+TfS)}{S(2H5+D)(1+TgS)(1+TfS)+Kt+1/R}$$

(1.6)

Where

Δf = closed-loop transfer function, PL = output integral (load)

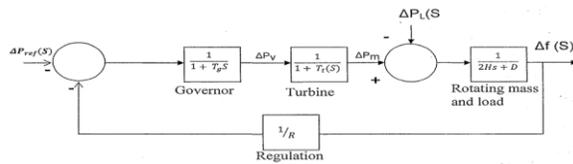
1/R = Regulation, Ts = Time constant for hydraulic gervometer valve

Tgs = Governor Transfer function, Tt(s) = Turbine transfer function

2H5+D = Rotating mass and load

D = Damping load constant transfer function

The figure (1.4) shows the dynamic model of a power system without AGC controller. This is represented below in order to know the impact of AGC in a single area power system



2.1 MODEL CONTROL CENTER

The basic objective of supplementary control is to restore balance between each area load and generation. Another requirement of AGC action is that a control signal to a given area should ideally correct only for changes in that area. Since controlled value is frequency and tie line power flow, it is naturally to make deviation of these two values, as controller input signal.

This signal is known as area control error (ACE) described by equations (1.7) and (1.8)

$$ACE1 = (\Delta P_{12} + B_1 \Delta F) \tag{1.7}$$

$$ACE2 = (\Delta P_{11} + B_2 \Delta F) \tag{1.8}$$

Where B is the bias factor of the two-control area respectively

2.2 AMPLIFIER MODEL

The excitation system amplifier may be a magnetic amplifier, rotating amplifier or modern electronic amplifier. The amplifier is represented by again KA

and a time constant TA, and the transfer function is

$$\frac{VR(s)}{Ve(s)} = \frac{KA}{1+TAS}$$

(1.9)

Typical values of KA are in range of 10 to 400 and TA range 0.02 to .0.1 second.

2.3 EXCITER MODEL

There is a variety of different excitation types, however modern excitation systems uses AC power source through solid - state rectifiers such as SCR. In the simplest form, the transfer function of a modern exciter may be represented by a single time constant TB and a gain KE

$$\frac{VR(s)}{Ve(s)} = \frac{KA}{1+TBS} \tag{1.9}$$

2.4 GENERATOR MODEL

The synchronous machine generated EMF is a function of the machine magnetization curve, and its terminal voltage is dependent on the generator load, in the linearized model, the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain KE and a time constant TG is given as

$$\frac{VR(s)}{Ve(s)} = \frac{KA}{1+TGS} \tag{1.10}$$

These constants are load dependent, KG may vary between 0.7 to 1.0, and TG between 1.0 and 2.0 seconds from full - load to no - load.

2.5 SENSOR MODEL

The voltage is sensed through a potential transformer and, in one form, it is rectified through a bridge rectifier. The sensor is modeled by a simple first order transfer function, give by

$$\frac{VR(s)}{Ve(s)} = \frac{KA}{1+TRS} \tag{1.11}$$

TR is very small and may be assume a range of 0.01 to 0.06 second hence, utilizing the above models results in the AVR block diagrams shown in figure 1.6

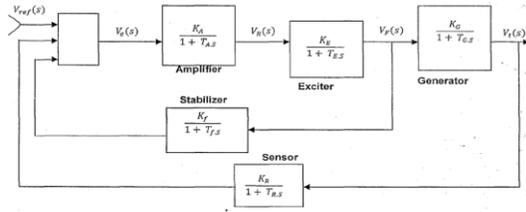


Figure 1.5 Simplified Automatic Voltage Regulator Model

2.6 ENHANCED AUTOMATIC VOLTAGE REGULATOR

Due to unsatisfactory step response of AVR, a controller is designed to increase the relative stability and add a zero to the AVR open-loop transfer function which is done by adding a rate feedback to the control system as shown in figure 2.6

. By proper adjustment of K_F and T_F , a satisfactory response can be obtained.

$$G_{PID}(s) = P + I + D = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s \quad (1.12)$$

where E_s is the error variable between the desired and real process output which produces the control signal U_s by computing the sum of proportional term P , integral term I and derivative term D .

The three design parameters of this controller, i.e., proportional gain K_p , integral gain K_i and derivative gain K_d , must be tuned jointly by the operator depending upon the plant's dynamics.

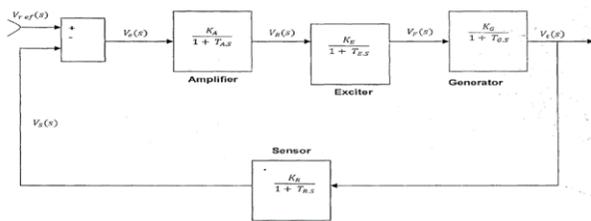


Figure 1.6 Block Model of the Compensated AVR System

II. SIMULATIONS

One-area system parameters on a 1000mva common Base

Table 1.2 One-area system parameters

Parameter	Value
Speed regulation	$R = 0.05$
Frequency sensitive load coefficient	$D = 0.8$
Turbine time constant	$T_1 = 0.5$
Governor time constant	$T_g = 0.2$
Inertial constant	$H = 5.0$
Integral controller K_1	$K_1 = 8.0$
Sudden change in load PL	$PL = 0.2$
Speed regulation $R_1 = 0.05$	$R_2 = 0.0625$
Frequency sensitive load coefficient $D_1 = 0.6$	$D_2 = 0.9$
Turbine time constant $T_{t1} = 0.5$	$T_{t2} = 0.6$
Governor time constant $T_{g1} = 0.2$ second	$T_{g2} = 0.3$
Inertial constant $H_1 = 5.0$	$H_2 = 4.0$
Integral controller $K_{i1} = 0.3, 0.6$	$K_{i2} = 0.3, 0.6$
Sudden change in load PL, $PL_1 = 0.2$	
Power transfer $P_s = 2.0$	
Frequency bias factor $B_1 = 0.3, 0.6$	$B_2 = 0.3, 0.6$

Table 1.3 Two area system parameters on a 1000MVA common base

GAIN	TIME CONSTANT (SEC)
Amplifier $K_A = 10.12$	$T_A = 0.1$
Exciter $K_E = 1.0$	$T_E = 0.4$
Generator $K_G = 1.0$	$T_G = 1.0$
Sensor $K_R = 1.0$	$T_R = 0.05$
Reference voltage	240V

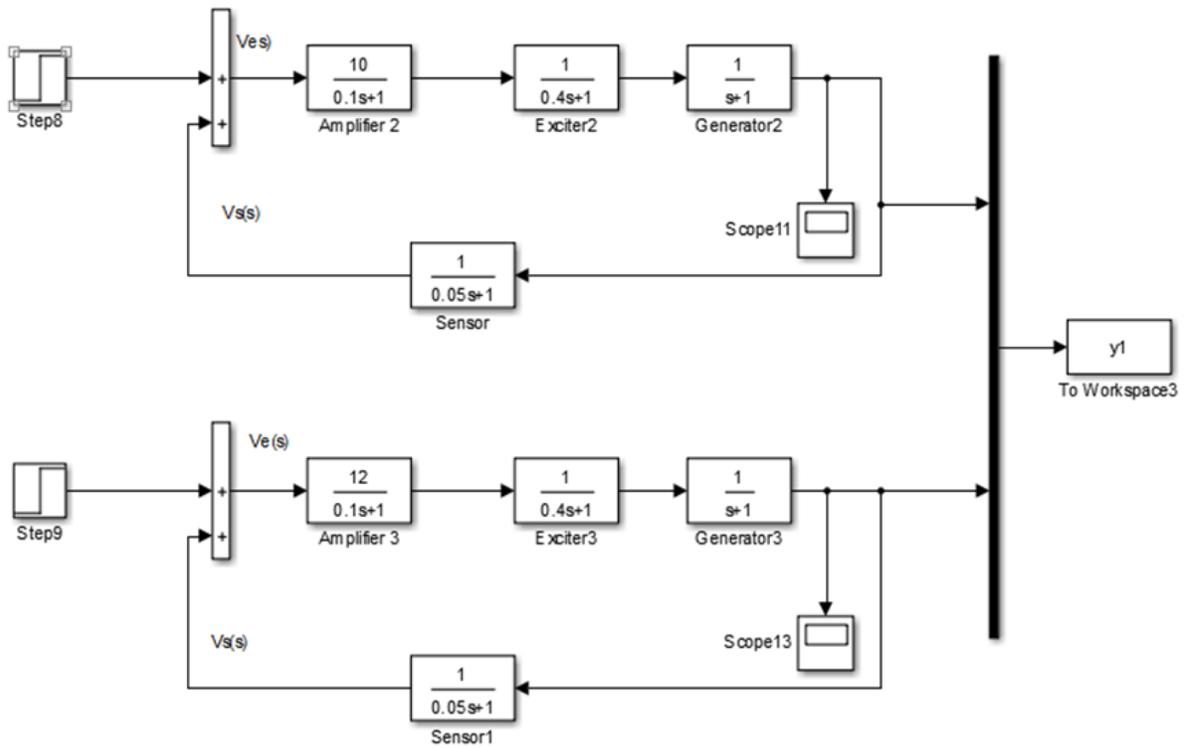


Figure 1.7 Simulink Model of Uncompensated AVR Block Diagram With $k_a = 10.12$

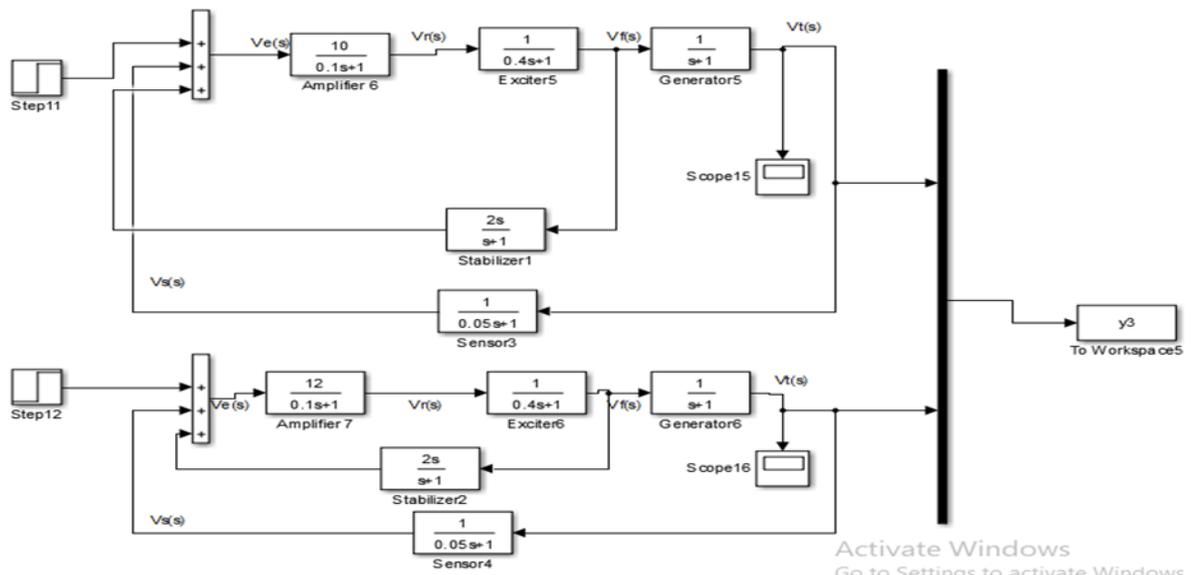


Figure 1.8 Compensated AVR Block Diagram with $k_a = 10.12$

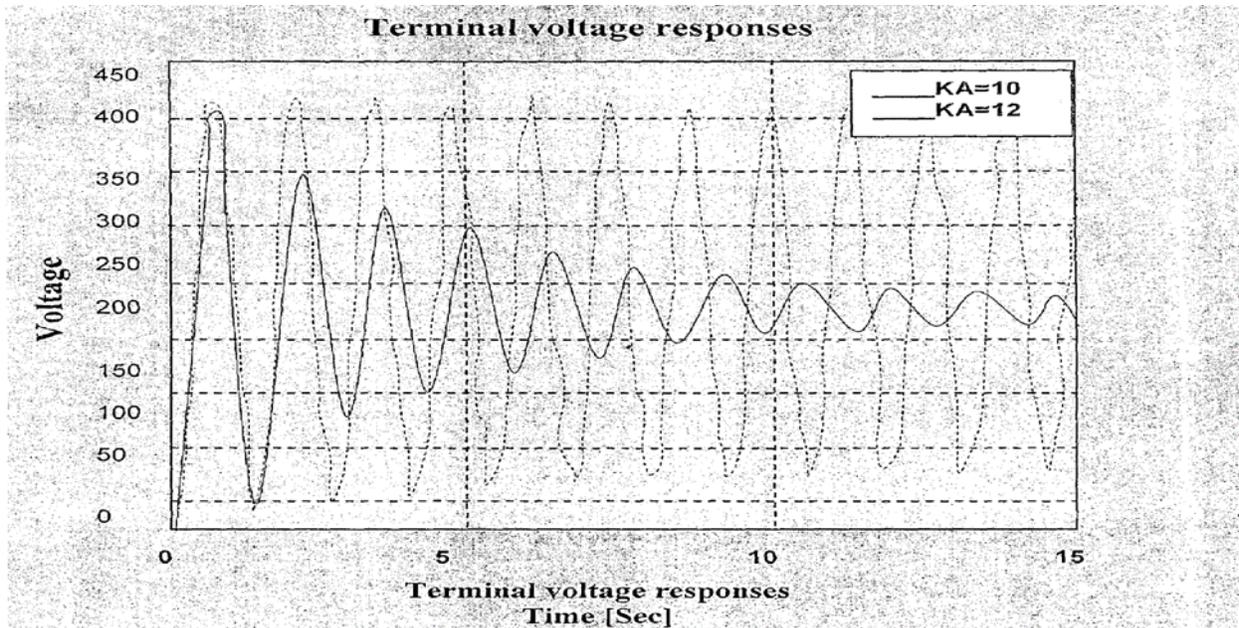


Figure 1.9 Terminal Voltage Response of Uncompensated AVR with Variation of KA, Voltage 240V

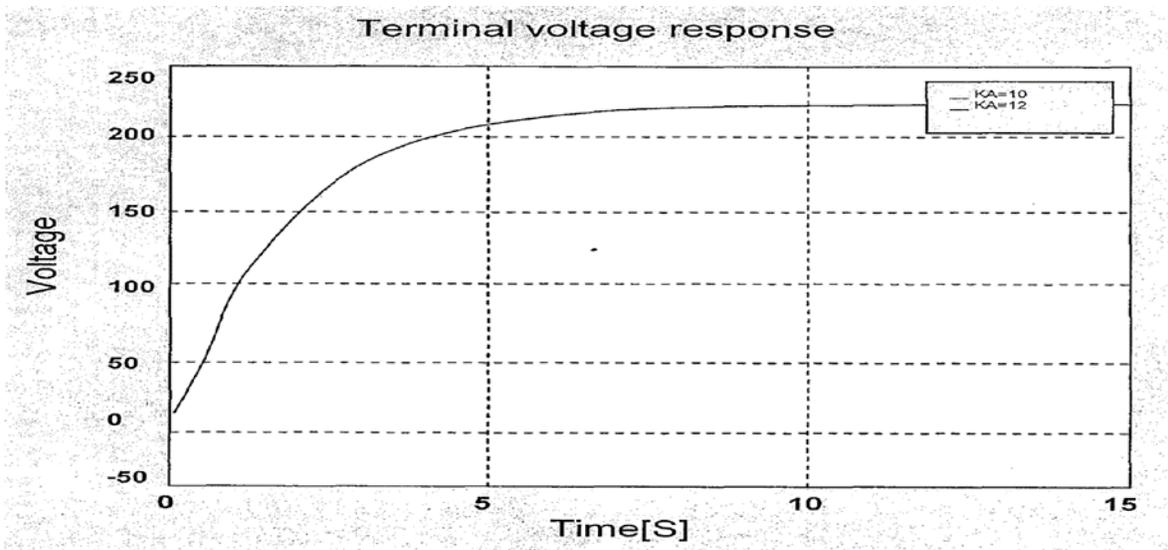


Figure: 1.10 Terminal Voltage Responses of Compensated AVR with Variation of KA.

figure 1.7.

RESULT AND CONCLUSION

CASE 1, VOLTAGE RESPONSE OF AVR WITHOUT COMPENSATION

In this case, different values of amplifier gain were varied both with stabilizer and without compensated AVR with system parameters in Tables 1.2 and 1.3.

The first case (case 1) is of AVR without compensation and compared model are shown in

As it can be seen from figure 1.9, a step change in terminal voltage 240V, at a time 15 seconds, the response of terminals voltage is highly oscillatory, with a very large overshoot and no settling time.

Hence, the higher the amplifier gain of an AVR without compensation the highly the oscillation response (i.e. higher in amplitude of oscillation).

CASE 2, VOLTAGE RESPONSE OF AVR WITH

COMPENSATION

Moreover, the second case (case 2) is of AVR with stabilizer (compensator). In figure 1.8, a compensated AVR and excitation system simulation model is shown. It can be seen in figure 1.10 and equation (1.12), that at a time 15 seconds following a step change in terminal voltage (V_t) 240V, the system is stable with settling time of approximately 5 seconds (desired value).

- [8] J.Tamura, T. Murata and I. Takeda,(2011),”New Approach For Steady State
- [9] Stability Analysis of Synchronous Machine”, IEEE Transaction on Energy Conversion, Vol.3,323-330, p 9.
- [10] S. Chatterjee, V. Mukherjee, (2016) PID controller for Automatic Voltage Regulator using teaching–learning based optimization technique, Int. J. Electr. Power Energy Syst. 77 418–42

REFERENCES

- [1] Armando Lamas and Jaime De La Ree,(2010),”Stability and The transient Energy Method For the Calsroom”, IEEE Centre for Power Engineering,79-85.
- [2] Atuchukwu A.J, Uzowulu, Ifeanyi Nnand and Iloh John Paul (2019), Reactive Power Compensation for Reduction of Losses in Nigeria 330kV Network Using Static Compensator (STATCOM). JUL 2019 | IRE Journals | Volume 3 Issue 1 | ISSN: 2456-8880.
- [3] Chao, x. Jinling, L. and Jinlong z. (2014), A Control Strategy for Transient Stability Improvement of Doubly-fed Wind Power Generation System, Advanced Materials Research; Vol. 953-954, p347
- [4] K.M (2015), Stability Study of Power System, International Journal of Energy and Power Engineering Vol. 4, No. 2, pp. 43-50.
- [5] Odubiyi, A and Davidson, I.E. (2007), “Managing the deregulation and privatization of the Nigerian electricity industry,” African Conference in Africa, 2002. IEEE AFRICON. 6th, vol.1, No1 pp 467- 472
- [6] Saver, P. W. and Pai, M. (2009), Power System Dynamics and Stability, Press New Jersey Scholten, (2013), Power Supplies for Automotive Start/Stop Systems, Edn Europe; Vol. 9, P34
- [7] Yinsheng, S.U., Junfeng, Z. and Xiaoming 11(2014), Enhance Power System Transient Voltage Stability by Difference Coefficient of Generator Excitation System Optimization, Advanced Materials Research, Vol. 1008-1009, p 409