ISSN: 2449 – 0539
BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY (BJET) VOL.15 No.3, AUG, 2020 PP 90-99

IMPACT OF CIRCUIT PARAMETRIC CHANGES IN LINEAR AND NONLINEAR STATCOM CONTROL SYSTEMS

Bala Boyi Bukata[1]

[1]Department of Electrical Engineering, Bayero University Kano, P. M. B. 3011, Nigeria

ABSTRACT

This paper proposes design of proportional-plus-integral-plus-derivative (PID) controllers for a linear and nonlinear static compensator (STATCOM) model using Ziegler Nichols (ZN) tuning method. The design is further extended to a nonlinear fuzzy-proportional-plus-derivative (FPD) control scheme. Comparison between the crisp PI, crisp PD, and Fuzzy PD was simulated in Matlab/Simulink environment with varying circuit parameters such as resistance, inductance, and capacitance for the linear and nonlinear setup. The results showed that the FPD is more robust in handling those changes against its counterparts. The study is particularly important in determining the choice of a control regime for solving power quality (PQ) problems in the advent of a smart grid.

Keywords: STATCOM; Fuzzy PD; Crisp PI; Crisp PD; Smart Grid.

1. INTRODUCTION

A given transmission line may be modeled by its series resistance, series inductance or inductive reactance, shunt (parallel to ground) capacitance or capacitive reactance, and leakage resistance (which is usually negligible) as: short line (up to 50 km; < 20 kV), medium line (up to 50 – 150 km; > 20 kV < 100 kV), and long line (>150 km; > 100 kV), for the purpose of system analysis, EPRI (1982). Although, line resistance and inductive reactance are important, for short transmission lines it is possible to omit the shunt capacitance and conductance and thus simplify the equivalent circuit considerably. But, the effects of each of them were considered under this work.

Bulk power carriage to the distribution centers is aided by means of increased line capacity as it reduces losses per unit transmitted power. Reduction in power losses is highly desirable because it conserves energy. The resistance of the conductor is the most important cause of power loss in a power line. There is well known formula for calculating the direct current resistance in a circuit as in, El-Hawary (2008). This formula however, is associated with some certain constraints for proper usage. For example, the following factors need to be considered:

i. Skin effect due to non uniform flux distribution in the conductor leads to non uniform current distribution to the surface of the conductor which in turn increases the resistance of the conductor.
ii. Effect of conductor stranding.
iii. Effect of resistance of magnetic conductors varying with current magnitude.
iv. Proximity effect due to non uniformity of current distribution caused by a higher current density in the elements of adjacent conductors nearest each other than in the elements farther apart.

Conversely, in transmission lines the inductive reactance is by far the most dominating impedance element. The literature has covered details on inductance for both single and three phase circuits, as well as for symmetrical and unsymmetrical bundle of conductors, for instance El-Hawary (2008), Andersson, et al. (2005).

In contrast, the capacitance of a transmission line is the result of the potential differences between the conductors themselves, as well as potential differences between the conductors and ground.

It was previously seen how two line parameters (resistance and inductance) constitute the series impedance of the transmission line, in which the line inductance dominates the series resistance and determines the power transmission capacity of the line. There are two other line parameters whose effects can be appreciable for high transmission voltages and line length i.e., the line's shunt admittance consisting of the conductance (g) and the capacitive susceptance (b). However, the conductance of the line does not constitute a major concern since it is dominated by the capacitive susceptance (b = ωC). Thus, the line capacitance is a leakage (or charging) path for the ac line currents. Therefore, charges on conductors arise, and the capacitance is the charge per unit potential difference. Because we are dealing with alternating voltages, we would expect that the charges on the conductors are also alternating (i.e., time varying). The time variation of the charges results in what is called line-charging currents again, Andersson, et al. (2005). It is reasonable at this point to assert that each of these parameters can affect power delivery to the distribution corridor in different ways.

The aim of this research is to investigate how each one of these parameters impact the system and provide the best way to mitigate any negative impact through redesigning the structural STATCOM controller. Hence, the objectives of the paper are realised by developing linear and nonlinear models of STATCOM suitably placed at the point of common coupling (PCC). Each of the models is equipped with a traditional Proportional - Integral (PI), Proportion - Derivative (PD), and Fuzzy Proportional - derivative (FPD) control strategies in the feedback. STATCOM can give quick and productive responsive power backing to keep up power system voltage soundness, Anjan and Nagrale (2016).

Validity of the STATCOM model was established through comparison between first-order-plus-delay-time (FOPDT) model and a real SimPowerSystems model developed in Matlab/Simulink environment.

The performance of these controllers are then simulated and compared for the aforementioned distribution parameters in a Matlab/Simulink environment. The superiority of the FPD controller is vividly observed in a number of established scenarios with varying conditions.

2. MATERIALS AND METHODS

This section presents the procedures and methods used in designing conventional Proportional-plus-Integral (PI), Proportional-plus-Derivative (PD), and Fuzzy Proportional-plus-Derivative (FPD) controllers for STATCOMs. The controllers will be used to study the impact of each of the three parameters on the transmission line constants due to load changes. Three scenarios, namely changes due to circuit resistance, circuit inductance, and circuit capacitance were developed and presented in section 3 to deal with such impact.

2.1 Nonlinear STATCOM Model

Firstly, the nonlinear mathematical model of (1) is very common to the literature e.g., Rashid (2001), it characterizes the dynamics of the STATCOM.

$$\frac{d}{dt}\begin{pmatrix} i_q \\ i_d \\ v_{dc} \end{pmatrix} = \begin{pmatrix} -\frac{R}{L} & \omega & 0 \\ \omega & -\frac{R}{L} & \frac{m}{L} \\ 0 & \frac{m}{c} & 0 \end{pmatrix}\begin{pmatrix} i_q \\ i_d \\ v_{dc} \end{pmatrix} + \frac{V_s}{L}\begin{pmatrix} -\sin\alpha \\ \cos\alpha \\ 0 \end{pmatrix} \quad \cdots \quad (1)$$

However, the reference used here defined the dq0 transform with respect to the rotor axis by first representing the quadrature axis current (iq) rather than the direct axis current (id) as shown in the equation. Equally, (1) can be simplified into (2) whenever alpha approaches zero $(\alpha \to 0)$ thus becomes small, then the sine function equals to zero, and cosine function approximately equals to 1. Other assumptions made towards linearising this equation are; zero harmonic generation and introduction of an infinite parallel resistance.

The system input applied to the STATCOM is a switching angle α, in radians. The output to the system is

ISSN: 2449 – 0539
BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY (BJET) VOL.15 No.3, AUG, 2020 PP 90-99

a voltage ahead of a reactive current component. The plant parameters used in simulation are specified a-priori according to Table 1.

2.2 Linear STATCOM Plant Specifications

Consider the third-order nominal DSTATCOM plant model represented by (2), and a characteristic equation (3) identified through some specified parameters given in Table 1.

$$G(s) = \frac{161300s^2 + 161300s + 6.88e^{10}}{s^3 + 2s^2 + 224700s + 35.56} \quad \cdots \quad (2)$$

$$s^3 + 2s^2 + s\left[\omega^2 + \frac{R^2}{L^2} + \frac{m^2}{LC}\right] + \frac{R}{L^2C}m^2 = 0 \quad \cdots \quad (3)$$

Table 1: Linear and Nonlinear Plant Parameters

Parameter	**Value**
Frequency (f)	50Hz
Resistance (R)	1Ω
Capacitance (C)	550µF
Inductance (L)	3mH
Total reactance ($jX = X_c + X_l$)	5.13Ω
Feeder ac – voltage (V)	415/220V
Modulation index (m)	1
Angular frequency (ω)	377rads/s
Switching angle (α)	±30° (±5326) rads
Reactive current (i_q)	38A
Direct current (i_d)	0.2A
Capacitor-link dc voltage (V_{dc})	380V

It is apparent that the solution to (3) yields three roots comprising of a real pole and a pair of complex eigenvalues. These roots have negative real parts, suggesting a damped and stable STATCOM, Bhim, et al (2015) which can conveniently be represented by a first-order plus delay time (FOPDT) plant. The desired goal for this application is that a step input produces a closed-loop output signal with an:

- Maximum overshoot of 20%
- Rise-Time of at most 1.05 seconds
- 27 seconds settling time
- Zero steady state error

This plant model is referred to as a Type-1 system which does not exhibit steady state error with constant inputs because of infinite positional error constants, Tewari (2002). Hence, it must be equipped with a free integrator in the forward loop to cancel the zero before it could effectively be controlled.

2.1.1 Generic PID Control Paradigm

Figure 4 from Bukata (2012), presents a generic PID - STATCOM closed-loop control circuit to serve as a first step towards the linear control design.

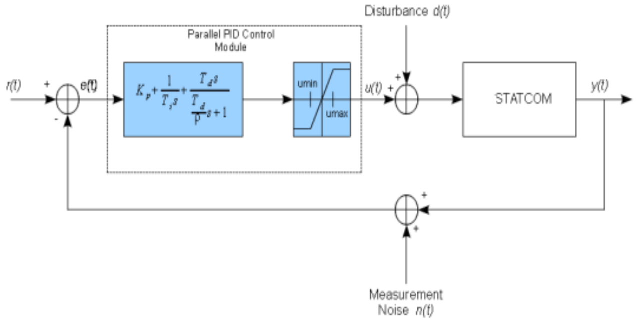

Figure 1: Generic closed-loop control system

The PID control rule u_{PID} defined in terms of the controller coefficients and the system error is given as Bukata (2012):

$$u_{\mathrm{PID}} = K_{\mathrm{p}}\left[e(t) + \frac{1}{T_{\mathrm{i}}}\int_0^t e(t)dt + T_{\mathrm{d}}\frac{de(t)}{dt}\right] \quad \cdots \quad (4)$$

Where, e(t) = r(t) - y(t), and r(t) is the reference signal. The disturbance d(t), normally is associated with the control output and transferred back into the system along with the reference input.

2.1.2 PID Tuning Methods

In practical PIDs, the integral and derivative time constants are tuned to drive the control action using Ziegler-Nichols (Z-N) method. Although, other methods such as; Amigo, CHR and PIDeasy tuning rules are also available. For its simplicity, Z-N was preferred in this research to identify and tune the linear model for the STATCOM in the next section.

2.1.3 Linear Model Identification

This section uses Ziegler-Nichols approach to identify the equivalent first-order-plus-delay-time (FOPDT) model needed for approximating the initial PID parameters, as in Bukata (2012). Parameters of interest

ISSN: 2449 – 0539
BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY (BJET) VOL.15 No.3, AUG, 2020 PP 90-99

like, system gain k, time delay t and the time constant τ are easily read off from Figure 2. The negative intercept $a = kL = \tau$, suggest non-minimum phase characteristics for the STATCOM. Since it is difficult to deal with a real transmission network, the input - output data was extracted from the open-loop step response simulation of the linear mathematical plant model defined earlier, to produce the FOPDT model in (5).

$$H(s) = \frac{ke^{-sL}}{1 + sT} \quad \cdots \quad (5)$$

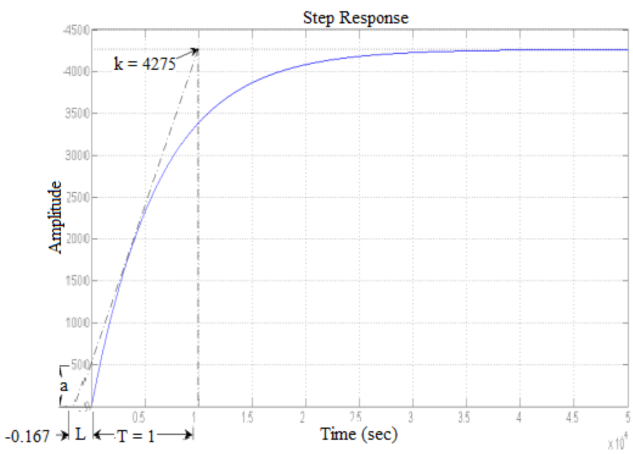

Figure 2: Heuristic Z-N Controller Design

From the closed-loop simulation, it is observed that the integrator introduced by the controller has been eliminated and thus reduced the control system (Gc) into a simple proportional-derivative system. The effectiveness of the initial control parameters can vividly be seen from the error plot (dotted green) tending to zero shown in Figure 3. This indicates their sufficiency in controlling a stable and damped system. This investigation is further extended to the performances of unstable plants as well as to plants with integrators enforced by uncertainties during steady state operations.

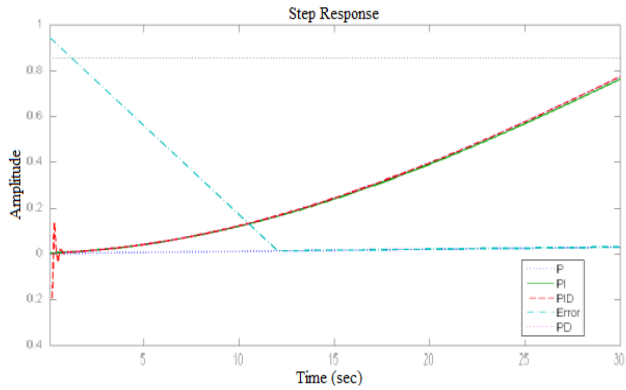

Figure 3: Initial FOPDT tuned responses

The numerical values of the parameters can thus be determined directly from Table 2 as the initial PID tuning rule with a = kL=T = 714. And the resulting closed loop control system obtained using this value is Gc(s) with controller H(s), and the original plant $G(s)$, both calculated from the first principles can be defined as:

$$H(s) = \frac{0.00012s^2 + 0.0014s + 0.0028}{s} \quad \cdots \quad (6)$$

$$G(s) = \frac{161300s^2 + 161300s + 1.516e^{005}}{s^3 + 2s^2 + 224700s + 35.56} \quad \cdots \quad (7)$$

$$Gc(s) = \frac{HG}{1 + HG} = 0.00012s + 0.0014 \quad \cdots \quad (8)$$

Tuning algorithms can then be simply formulated for time domain response from Table 2 in order to simulate the system's response to a given input step signal .

Table 2: Ziegler-Nichols Emperical Tuning

Controller	Tuning Rules			Initial Parameters		
	K_p	T_i	T_d	K_p	T_i	T_d
P	$1/a$	-	-	0.0014	-	-
PI	$0.9/a$	$3L$	-	0.0012	0.501	-
PID	$1.2/a$	$2L$	$L/2$	0.0016	0.334	$0.0835L$

2.2 Nonlinear Fuzzy PD Control System Design

Figure 4 depicts the FPD control system. It consists of a pre-processor, fuzzification, rule base, inference engine, defuzzification, and post-processor blocks. The inputs to the fuzzy controller are the voltage error, and rate of change of that error. The output is the switching angle of

ISSN: 2449 – 0539
BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY (BJET) VOL.15 No.3, AUG, 2020 PP 90-99

the converter. The FPD is fabricated using three (3) production *if…then* rules of the form:

- If error is positive and the rate of change in error is high then reduce switching angle.
- If error is zero and the rate of change of error is low then maintain switching angle (No action required).
- If error is negative and rate of change of error is medium then increase switching angle.

This formulation is based on experience and has the advantages of saving computer memory resource, eliminates redundant rules, as well as increases processing speed.

In practical STATCOM, this procedure offers great flexibility in tuning the nonlinear function implemented. The non-minimum phase systems (such as being dealt with here) can impose fundamental limitations from achieving preset control objectives no matter how well the fuzzy controllers are tuned, Siriki and Rajesh (2018). Nevertheless, a reasonable choice of control inputs and output usually provide a good tuning premise on the scaling factors. This section makes proper investigation of each of these factors and the way they influence fuzzy controller response.

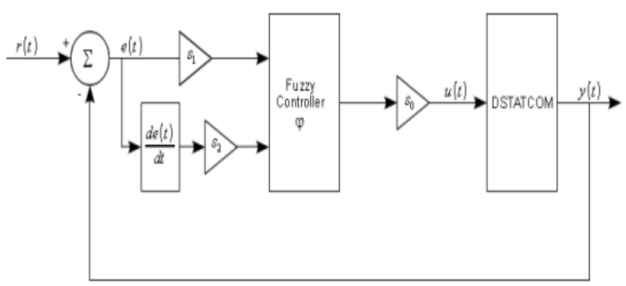

Figure 4: FPD – DSTATCOM control model

2.2.1 Input-Output Scaling Factor Tuning

Reference to Figure 4, the scaling factors S_1, S_2 and S_0, are set of notable tuning factors that largely influence fuzzy decision process at the system's input and output ports in accordance with the chosen inferencing procedure. The tuning process is initialed by arbitrarily setting the first input scalar (S_1) as an inverse of the setpoint value from Ng (1995) as

$$X_e = \frac{22}{e_{\max}} e(k) = S_e e(k) \quad \cdots \quad (9)$$

Where e_{max} represents the step size of the error signal which in this case is ±5% of 220 volts (i.e., ±11 kilovolts), measured against the distribution feeder standard nominal supply normally supplied to the consumer's terminal in Nigeria (Provision of IEEE Std 3001.2.2017). Xe is the fuzzified set of the error variable. Note that Eq. 7 is similar to the traditional proportional controller $u_p(k) = K_p e(k)$. Then, the second input scaling parameter for the error derivative $S\dot{e}$ given in (10), is continually modified through an empirically acquired value of $\dot{e}_{max}$ from the process dynamics. This action is suppose to normalise the fuzzy set $X\dot{e}$ of the derivative input calculated from the gradient of the original error curve in the range ± 0.5 volts/sec.

$$X_{\dot{e}} = \frac{0.5}{\dot{e}_{\max}} \frac{\Delta e(k)}{\Delta t} = S_{\dot{e}} \frac{\Delta e(k)}{\Delta t} \quad \cdots \quad (10)$$

Meanwhile, the output scaling factor, $S\alpha$ is linearly varied from zero to its maximum value.

$$\alpha_c = \frac{\alpha_{c\max}}{X_{c\max}} X_c = S_\alpha X_c \quad \cdots \quad (11)$$

Where, α_c is the crisp control output (plant input), and α_{cmax} its maximum value. The action of the control output due to fuzzifying a fuzzy set (i.e. Low) in the universe of discourse and its maximum values are denoted by X_o and X_{omax}, respectively. The control output is issued as a switching angle (α) designed to saturate beyond some threshold in the dynamic sine-cosine operating range of the STATCOM established as $\pm 30^{o}$ or ± 0.5326 radians. The benefit of the dynamic range is seen where the STATCOM can be applied at the transmission corridor as illustrated in Figure 5.

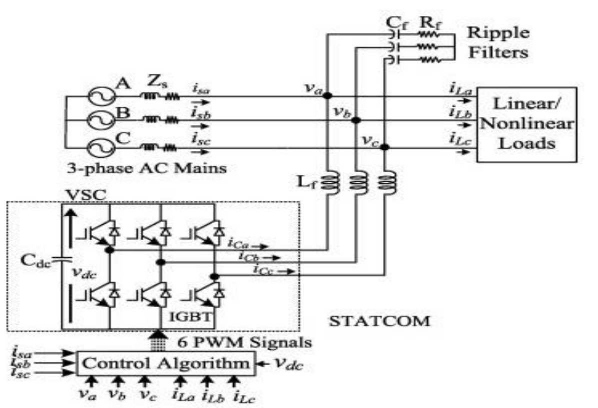

Figure 5: DSTATCOM Switching Function Bhim, et al (2015)

3. RESULTS AND DISCUSSION

This section presents and discusses in three scenarios, the effects of the aforementioned parameters due to system's load changes. Different control strategies were designed and deployed to deal with any ensuing system instability. The study covers both linear and nonlinear models responses to the same controllers. The results were subsequently tabulated and compared. Model validation was also performed between the simulation model and the real model developed in SimPowerSystems software.

3.1 Scenario No. 1: Changes in circuit Resistance

The change in circuit resistance is akin to uncertain parameter gain changes which is bound to raise the gain margin by introducing a transfer zero capable of speeding up the system and causing overshoot. This situation has been depicted in Figure 6, when the circuit resistance was changed from 1Ω to 3Ω. By applying a step signal of 220kV to the nonlinear STATCOM in a closed-loop, the responses from the PI (green) and PD (maroon) controllers are noticed to stagnate at 180kV. While with the same control effort of 0.01129 radians, the fuzzy controller (red) stabilizes the system at zero error and zero overshoot. However, the linear STATCOM responses for the PI and PD controllers produced no overshoot as in Figure 7, although the magnitude of the outputs drop to 200kV, again the fuzzy controller maintains its grip at 220kV through a control effort of 0.01364. The details of the system parameters used for this simulation are listed in Table 3 for both linear and nonlinear models.

Table 3: Model Performance due to uncertain resistance change

Parameter	Nonlinear Model Resistance Change			Linear Model Resistance Change		
	PI_{NL}	PD_{NL}	FPD_{NL}	PI_L	PD_L	FPD_L
S_1	0.0011	0.0011	0.0011	1.0011	1.0011	1.0011
S_2	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
S_o	2.7600	2.7600	2.7600	2.7278	2.7278	2.7278
α	0.01129	0.01129	0.01129	0.01364	0.01364	0.01364
e	$2.71e-5$	$2.71e-5$	$2.71e-5$	0	20.0	20.0
$\dot{e}$	0	0	0	0	4.462	4.462
V	180	180	220	220	200	200

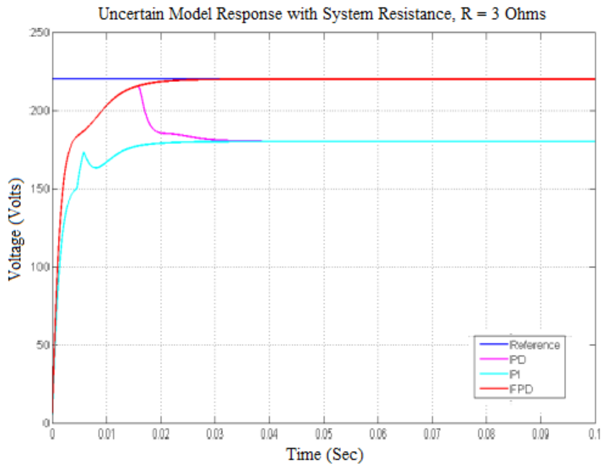

Figure 6: Effect of nonlinear change in resistance

Nonlinear model: R = 3Ω

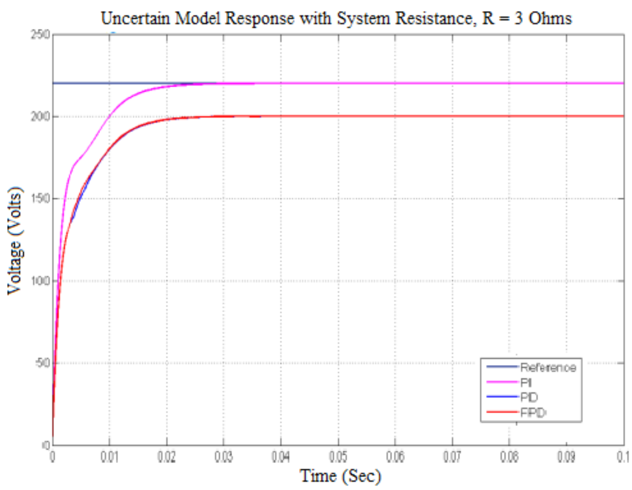

Figure 7: Effect of linear change in resistance

Linear model: $R = 3\Omega$

3.2 Scenario No. 2: Changes in Circuit Inductance

For a situation where a nonlinear STATCOM model is equipped with one or more extra zeros at the numerator, the control action would need to place some poles (pole placement) in order to supplement for zero cancellations. Figures 8 and 9 depict the respective scenarios in a nonlinear and linear model, where the fuzzy PD (red) stabilizes the steady state error as $\alpha \Rightarrow 0$ in a closed-loop operation, given a setpoint following of 220kV command. The failure of the PD (maroon) and PI (blue) controllers is vividly seen when sudden drop in the magnitude (180V) occurred at t = 0.65 and t = 0.66 seconds, respectively. These changes were introduced into the system through some parametric alterations shown in Table 4.

Table 4: Model Performance due to uncertain inductance change

Parameter	Nonlinear Model Inductance Change			Linear Model Inductance Change		
	PI_{NL}	PD_{NL}	FPD_{NL}	PI_L	PD_L	FPD_L
S_1	0.0011	0.0011	0.0011	1.0011	1.0011	1.0011
S_2	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
S_o	2.7600	2.7600	2.7600	2.7338	2.7338	2.7338
α	0.01129	0.01129	0.01129	0.01367	0.01367	0.01367
e	0.04387	0.04387	$4.83e-5$	0.1422	0.1422	0.1422
$\dot{e}$	-0.000131	$0-0.000131$	-0.000131	-0.0046	-0.0046	-0.0046
V	180.2	180.2	220	220.5	219.5	220

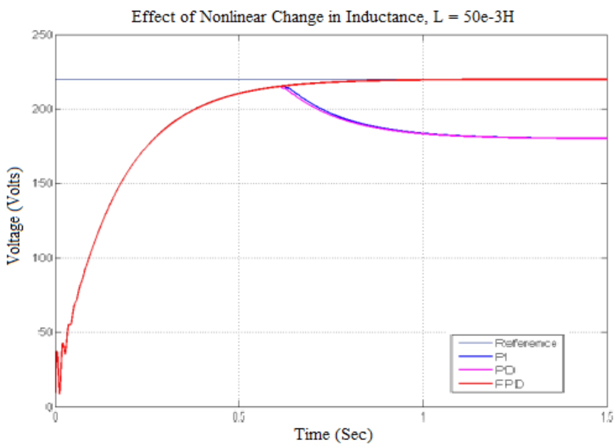

Figure 8: Effect of nonlinear change in inductance Nonlinear model: L = 50 mH

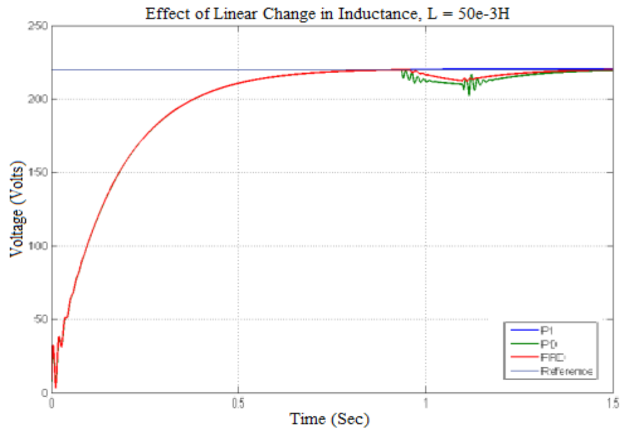

Figure 9: Effect of linear change in inductance Linear model: L = 50 mH

3.3 Scenario No. 3: Changes in Circuit Capacitance

This is a case of "type 2" nonlinear STATCOM with an extra pole at the origin in a long line representation. The circuit capacitance was raised to 1500μF from 500μF, while retaining the original circuit resistance and circuit inductance values. Step response closed-loop simulation of the nonlinear plant shown in Figure 11 depicts a PI (blue) controlled system infested with overshoot to the tune of 95.7%, rising at 0.0125 seconds and settling at 0.18 seconds. Although its performance is better than the PD (maroon) controller which exhibits a speed of 0.013 seconds, yet offers settling time of 0.17 seconds at 82.82% overshoot, lower than the PI. The fuzzy PD (red) can be seen to offer smaller settling time (0.14) and 0% overshoot at a little slower speed of 0.016 seconds. Similar observations are made when the linear system in Figure 12 is simulated, in which the performance of both FPD (red) and the PD (maroon) controllers are well behaved within reasonable speed, with restrained 0% overshoot limits. However, the PI (blue) controller characterises a 59% overshoot, pointing to its unsuitability even in the linear model, where it is ubiquitous today. While Table 5 presents circuit parameters obtained for describing the scenario.

Table 5: Model Performance due to uncertain capacitance change

Parameter	Nonlinear Model Capacitance Change			Linear Model Capacitance Change		
	PI_{NL}	PD_{NL}	FPD_{NL}	PI_L	PD_L	FPD_L
S_1	0.0011	0.0011	0.0011	1.0011	1.0011	1.0011
S_2	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
S_o	1.1245	1.1245	0.9200	1.0226	0	0
α	0.004601	0.004601	0.0046	0.004184	0.004092	0.004092
e	0.02464	0.02464	$2.71e-005$	-0.04485	-0.04485	-0.0448
$\dot{e}$	0	0	$-1.075e-010$	0	0	-1.649
V	220	220	220	220	220	220

ISSN: 2449 – 0539
BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY (BJET) VOL.15 No.3, AUG, 2020 PP 90-99

3.4 Model Validation

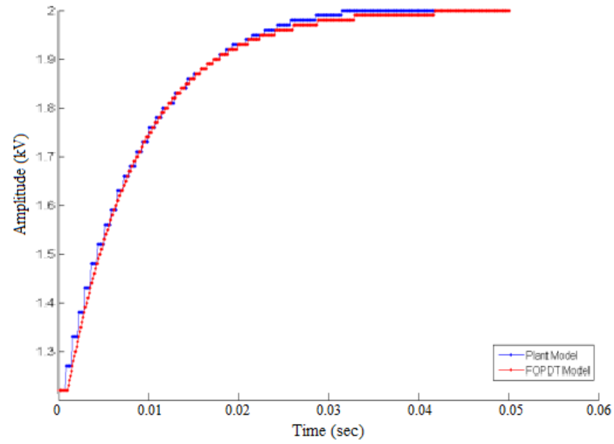

Figure 10: Model comparison

Figure 10 depicts validation of the simulation model in form of a first order plus delay time (FOPDT) model against the real model developed in SimPowerSystems software. This was done in order to ascertain the accuracy of the work.

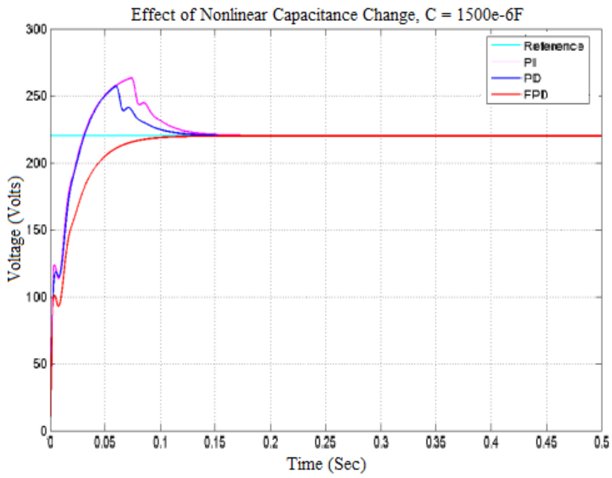

Figure 11: Effect of nonlinear capacitance change
Nonlinear model: C = 1500µF

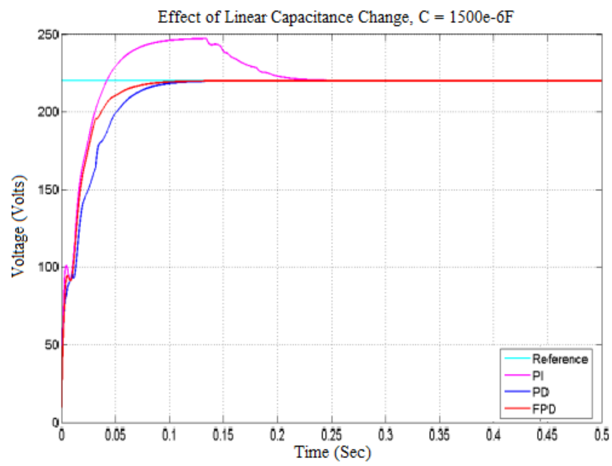

Figure 12: Effect of linear capacitance change
Linear model: C = 1500µF

3.5 Setpoint Following

Closed-loop performance based on CAD simulation targeted at a 220 kilovolt (long) line was investigated. Figure 13 shows step responses to both linear and nonlinear models controlled by PI (blue), PD (maroon) and the fuzzy PD (red). It is observed that the nonlinear fuzzy PD offers a faster response and a shorter settling time with no overshoot against both linear PI and linear PD controllers. Despite oscillations observed in the linear PD, yet it is faster than the linear PI controller justifying my earlier claim. The subscripts L and NL, denote linear and nonlinear model, respectively. It is noted that the nonlinear FPD model offers optimum control effort of 0.0046 rads. The results are displayed in Table 6. It is interesting to note the linear PI model overshoot kept at 0% and its nonlinear PI counterpart rose to 12.55%. This actually is a pointer to the huge success of the PI control application to DSTATCOM found in the literature.

However, its behaviour in the nonlinear model suggests a re-think for real-time application. Better alternatives are yet found in the linear and nonlinear FPD models reflecting 0.17% and 0.74% overshoot, respectively. It is observed that the linear model looks more promising.

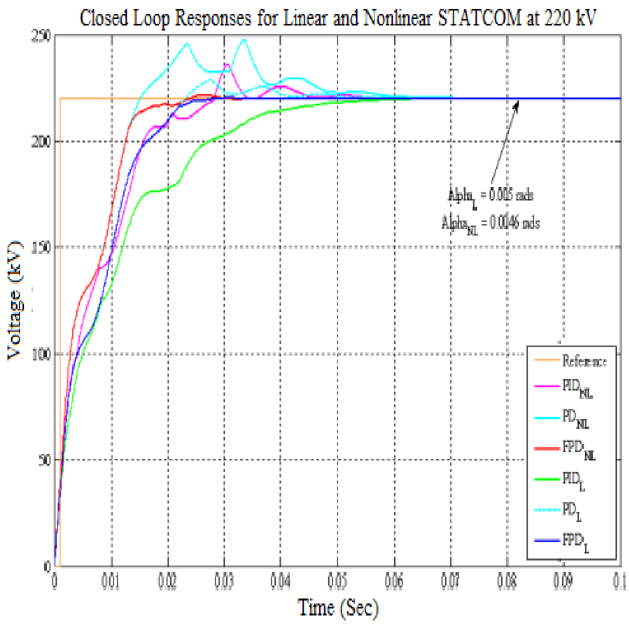

Figure 13: Linear vs. nonlinear model performance

Table 6: Linear (L) vs. Nonlinear (NL) Model Performance Indicators

Parameter	PI_L	PD_L	FPD_L	PI_{NL}	PD_{NL}	FPD_{NL}
P	1.163	10	1	1.163	10	1
I	0.5	0	0	0.5	0	0
D	0.01	0.001	0.01	0.01	0.001	0.01
e	-0.00793	-0.00794	$-ve$	$3.664e-005$	$3.664e-005$	$+ve$
$\dot{e}$	-1.619	-1.619	*Slow*	-0.00067	-0.00067	*Slow*
α	0.004091	0.004091	0.004091	0.0046	0.0046	0.0046
S_1	1.0011	1.0011	1.0011	0.0011	0.0011	0.001
S_2	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
S_o	0.9998	0.9998	0.9998	1.1241	1.1241	0.9200
$Overshoot\%$	0	3.96	0.17	12.55	7.34	0.74
$RiseTime(sec)$	0.011	0.008	0.008	0.0078	0.0074	0.0074
$SettlingTime(sec)$	0.078	0.065	0.03	0.080	0.086	0.05
$TargetOutput(volts)$	220	220	220	220	220	220

4. CONCLUSION

The philosophy behind this work is to investigate the effect of transmission line constants namely; resistance, inductance, and capacitance. It is aimed at preparing the Engineer as to having an idea of what should be anticipated in ensuing power quality problems in a given transmission line context. A STATCOM control strategy was considered and located at the transmission corridor. The linear and the nonlinear STATCOM models equipped with PI, PD, and Fuzzy FD control strategies in the feedback were developed and simulated in Matlab/Simulink environment. The results were successfully presented for varying parametric values. That, plus the setpoint following simulation proves the superiority of the Fuzzy PD controller over its conventional PI and PD controllers. It presents overshoots of 0.17% and 0.74% for nonlinear and linear, respectively. This may be read off from Table 6, and Figure 12.

5. REFERENCES

Bukata, B. B. (2012). Evolutionary Optimisation for Volt-VAR Power Quality Control (Doctoral Thesis, School of Engineering University of Glasgow, UK). Retrieved fromhttp://theses.gla.ac.uk/3882/.

El-Hawary, M. E. (2008). Introduction to Electrical Power Systems. Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

EPRI (1982). *Transmission Line Reference Book, 345 kV and Above*. Palo Alto, California: Electric Power Research Institute.

Andersson, G.. et al., (2005). Causes of the 2003 major grid blackouts in North America and Europe, and recommended means to improve system dynamic performance, *IEEE Transactions on Power Systems*, Volume 20, Issue 4, Page(s): 1922- 1928.

Bhim, S. et al., (2015). **An improved control algorithm of DSTATCOM for power quality improvement.** International Journal of Electrical Power & Energy Systems, **Volume 64**, Pages 493-504**.**

S. SIRIKI and S. RAJESH (2018). Fuzzy Logic Control of D-STATCOM for Improving Power Quality and Dynamic Performance. ISSN 2321-8665 Volume 06, Issue 02. Pages: 0487-0490.

S. P. Anjan and R. M. Nagrale (2016). Comparison Of Adaptive PI And PI Control of Statcom For Voltage Regulation". International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE) ISSN: 0976-1353 Volume 23 Issue 6.

M. H. Rashid (2001). *Power Electronics Handbook*. Academic Press Series in Engineering, 2nd edition.

Ashish Tewari (2002). *Modern Control Design*. JOHN WILEY & SONS, LTD.