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Electrical and Computer Engineering

DESIGN OF ADAPTIVE CONTROLLER FOR REGULATING THE VOLTAGE BY A DYNAMIC VOLTAGE RESTORER DVR

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Master's Thesis

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DESIGN OF ADAPTIVE CONTROLLER FOR REGULATING THE VOLTAGE BY A DYNAMIC VOLTAGE RESTORER DVR

by

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Saud N.Abdulazeez

DEDICATION

After all the difficulties that I've been through and overcome, I want to thank the people who helped me reach where am I now by mentioning their names gratefully in my thesis' dedication page:

My mother, Huda J Nezar

My father, Nashwan Abdulazeez

My three younger brothers: Hkm, Ali and Qasim.

My uncle, Dr.Adil J Nezar.

My aunt, Sundus J Nezar.

And lastly, my first and last love, Dr.Mina Badr.

I love you all.

Without you and your support, I wouldn't have been able to accomplish my master degree.

ABSTRACT

DESIGN OF ADAPTIVE CONTROLLER FOR REGULATING THE VOLTAGE BY A DYNAMIC VOLTAGE RESTORER DVR

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Speedy changes in the source of power could influence the loads performance like (1) semiconductor invention factories (2) paper grindery (3) food treatment factories and (4) automotive installation factories. The prevalent troubles in the power sources are the decreasing of voltage (sags) or the increasing of voltage (swells) this could be caused by (1) upsets emerge in the transmission arrangement, (2) collapse of approach feeders and (3) fuse or breaker procedure. Voltage decreasing (sags) of Ten percent standing for five to ten cycles can cause an expensive loads damage. To relieve the low quality problems of power equipping, the modifier of voltage source could be connected by transmission lines serial which put as compensators. Which are called Dynamic Voltage Restorer (DVR). This research is suggesting a new blueprint for DVR controller by applying an adaptive Neuro-fuzzy logic. As well as, the theory of momentary power is applied to estimate the voltage phase because of the great accuracy and low calculation for this theory. However, the results of simulation indicate the application of real-time on the suggested controller is powerful and potential comparison with traditional controllers which investigated previously.

Keywords: ANFIS, DVR, Fuzzy Logic, Theory of Momentary Power, TS controller

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LIST OF ABBREVIATIONS

ANFIS	:	ADAPTIVE NEURO-FUZZY INTERFERENCE SYSTEM
DVR	:	DYNAMIC VOLTAGE RESTORER
SSSC	:	STATIC SYNCHRONOUS SERIES COMPENSATOR
ANN	:	ARTIFICIAL NEURAL NETWORK
TS	:	TAKAGI-SUGENO
VSI	:	VOLTAGE SOURCE INVERTER
FACTS	:	FLEXIBLE AC TRANSMISSION SYSTEM
PI	:	FLEXIBLE AC TRANSMISSION SYSTEM
PLL	:	PHASE LOCKED LOOP SINUSOIDAL PULSE WIDTH MODULATION
PI	:	FLEXIBLE AC TRANSMISSION SYSTEM
SPWM	:	SINUSOIDAL PULSE WIDTH MODULATION

LIST OF SYMBOLS

ψ : THE PHASE ANGLE OF THE INJECTED VOLTAGE

π : 3.14

Δe : CHANGE OF ERROR

$\tilde{p}$: IS THE OSCILLATING VALUE OF THE INSTANTANEOUS ACTIVE POWER

$\overline{p}$: IS THE AVERAGE VALUE OF THE INSTANTANEOUS ACTIVE POWER

$\tilde{q}$: : IS THE OSCILLATING VALUE OF INSTANTANEOUS REACTIVE POWER Q, THAT IS EXCHANGED BETWEEN THE SYSTEM PHASES

$\overline{p}$: IS THE AVERAGE VALUE OF THE INSTANTANEOUS REACTIVE POWER IS EQUAL TO THE CONVENTIONAL REACTIVE POWER ($Q = 3V I \sin \Phi$).

1. INTRODUCTION

A power framework is a perplexing system more often than not involving various generators, transformers, transmission lines and loads. The electric power request keeps on developing and assemble the new producing units and transmission lines are ending up increasingly troublesome as a result of financial reasons and developing an open effect on a natural approach. As a result, a portion of the transmission lines is more stacked than was masterminded when they were built. With the extended stacking of long transmission lines, the issue of transient quality after an imperative deficiency becomes a transmission capacity to constraining component. Transient security is the capacity of the power framework to keep up the synchronism when exposed to a serious transient unsettling influence, for example, a deficiency on transmission offices, unexpected loss of age, or loss of a substantial burden [1].

The smart collections in the source voltage can affect the execution of the stacks, for example, (a) semiconductor produces plants (b) paper generation lines (c) sustenance preparing plants and (d) vehicle gathering plants. The run of the mill aggravations in the source voltages are the voltage hangs or voltage swells this can be an immediate consequence of (I) unsettling impacts creating in the transmission framework, (ii) nearby feeder deficiencies and (iii) wire or breaker activity. Voltage game plans of 10% proceeding for 5-10 cycles can result in preposterous fiendishness in the heaps. To coordinate the issues of low-quality power supply, a voltage source converter can be connected in blueprint with transmission lines as a compensator. These are known as Dynamic Voltage Restorer (DVR) or Static Voltage Restorer. The essential application is to compensate the voltage for voltage agitating impact which is; hangs and swells [2].

The DVR has four components: Voltage Source Converter (VSC), Boost or Injection Transformers, Passive Filters and Energy Storage [3-4], and the basic control strategies for DVR can be classified as:

1. Pre-Sag /Dip Reimbursement.
2. In-stage Reimbursement.
3. Least Energy Reimbursement.

The control strategies for DVR are discussed with details in chapter two of this thesis.

1.1 LITERATURE REVIEW

Rosli Omar and N.A Rahim in 2009 [5]. Presents the low voltage dynamic voltage restorer (DVR) in light of utilization of room Vector Pulse Width Modulation (SVPWM) for Voltage Source Converter (VSC). The control calculation is researched through PC reenactment by utilizing PSCAD/EMTDC programming. The DVR has demonstrated the capacity to adjust for voltage droops at the matrix side, this can be demonstrated through reenactment and test results. The low voltage model DVR was bolstered with a programmable AC control source 6560/6590. The model was appraised to a 5KVA burden a 30% voltage droops. Adjusted voltage droop was made following a deficiency, in burden, terminal voltages are reestablished through the pay by DVR.

Firouz Badrkhani Ajaei et al in 2011 [6]. Another control plot for the dynamic voltage restorer (DVR) was exhibited to accomplish quick reaction and viable hang pay capacities. Quick least blunder squares computerized channels were utilized to appraise the size and period of the deliberate voltages, additionally lessen the sounds, and unsettling influences on the assessed phasor parameters. Consequences of the reproduction examines in the PSCAD/EMTDC programming condition demonstrate that the proposed control conspire repays adjusted and unequal voltage lists in an exceptionally brief timeframe, with pay of 30% in a brief timeframe interim around 5 msec.

Pedro M. Garcia-Vite et al in 2013 [7 DVR dependent on vector– exchanging grid converter has been structured. The topology associates in arrangement with the dispersion feeder and is acknowledged by the fell association of a three– stage capacitor bank, a three– stage single– post double– toss switch. Recreation of list condition 1p.u. to 70% of these transport voltage, with a term list for around 10 cycles. And furthermore the instance of the decent voltage swells, of expanding of 25% was recreated, with a similar span as utilized for the voltage list. The well execution of the DVR under voltage droops and swells conditions exhibiting a worthy setting time and quick transient reaction of short of what one cycle, other than the invalid blunder in consistent state.

Li Wang and Quang-Son Vo in 2013 [8]. DVR has been designed for stability improvement and voltage control for SMIBS connected to offshore wind farm. A d-q frame and two reference signals from line current and phase voltage to perform the reactance of the line. A period space conspires dependent on a nonlinear framework show subject to an aggravation is additionally performed. The inborn low-recurrence motions of the SMIB framework can likewise be successfully smothered by the proposed control conspire. A PI controller has been intended for controlling DVR. From the simulation results shows the ability of DVR to improve the performance of the studied SMIB system under different operating conditions. Also effectively stabilize the studied system under an unstable condition.

Mohamed Shawky et al in 2014 [38]. DVR for reactance and series resistor compensator have been designed and simulated for enhancing the self-excited induction generator-based wind turbines that connected to single machine infinite busbar system (SMIBS). The capability of the two plans was assessed and investigated utilizing positive and negative-succession reference outlines because of adjusted and lopsided deficiency conditions. The reenactment results utilizing SCAD/EMTDC show the execution of the proposed plans for improving the transient strength edge by expanding the most extreme basic clearing time from 0.18 sec to in excess of 2 sec. The steady activities because of various kinds of lattice issues were checked. The plans have appeared and quick relief of voltage unsettling influence of around 1 cycle.

H.R. Chamorro and G. Ramos in 2011 [9]. A power stream control dependent on fuzzy controller plot for low voltage small scale matrices in matrix associated and island task mode has been structured. The usage of p-q theory for estimations of dynamic and responsive power exhibit a broad diminishing in the transient direct and can be associated in a future gear progression. The fuzzy method of reasoning in this system gives a general intend to be used in huge complex structures, in view of the p-q speculation are in time zone bringing more accuracy for power electronic applications and controllers and are material in transient wonders also. Reproduction demonstrates the momentary estimations present a superior accuracy in test time and this could improve the control activity because of the dynamic power scope of about 20% of the reference control additionally the receptive power was about 20%.

Wei Qiao et al in 2009 [10]. Presents a sensor assessment and reclamation conspire by utilizing auto-affiliated neural systems (auto encoders) and molecule swarm streamlining. The d-q outline used to play out the controller. An ongoing usage of a DVR associated with the IEEE 10-machine 39-transport framework on a Digital Simulator and TMS320C6701 computerized flag processor stage. The methodology for controlling a DVR associated with a power arrange. The DVR and power organize have been exposed to different framework unsettling influences. Results have demonstrated that the new structure accurately reestablishes the information from various missing current sensors, and gives shortcoming tolerant viable control to the DVR and the power organize amid unfaltering state, and transient condition of unequal and adjusted lattice blames just as a difference in burden conditions.

From the previous research studies it can be concluded:

Most of the researchers did not focus on the compensator response time, they satisfied on the performance and the principles of operation.

Other researchers were, satisfied with the simulation of the DVR without use of new control design.

In most of the researches, the response time to DVR in voltage regulation was about 20 msec (1 cycle).

1.2 AIMS OF THIS WORK

The aims of this work can be summarized as follows:

Validation of momentary power theory (p-q theory) for fast measuring active power, reactive power in less than 10 msec (less than half cycle) and for measuring voltage in less than 5 msec (less than quarter cycle), by simulation and practical tests.

Design DVR to enhance the voltage regulation and to compensate the phase voltage in sag/swell disturbance conditions.

Modify the DVR controllers' performance by using adaptive controllers which are; Adaptive Neuro-Fuzzy System ANFIS.

Simulating the DVR in voltage regulation by using Matlab/Simulink.

Comparing the results obtained from simulation with the conventional technique.

1.3 THESIS LAYOUT

This thesis falls into five chapters as follows:

Chapter One, Introduction, presents the point of the proposition, writing audit and thesis structure.

Chapter Two, DVR Operation, briefly introduces the modes of operation of the DVR. Also the range, voltage stability.

Chapter Three, DVR based momentary theory and Control, describes the types of measuring the voltage. Also describe the momentary power theory (p-q theory) in details. Design DVR control based on p-q theory for voltage regulation. Also, the chapter gave the details of two adaptive controllers were designed which are: Adaptive Neuro-Fuzzy System ANFIS and Takagi-Sugeno Fuzzy like PI controller. Also, the conventional PI controller was used to identify the Fuzzy like a PI controller.

Chapter Four, DVR Modeling and Simulation, the modelling of voltage regulation based on p-q theory was presented in this chapter. Modeling DVR in voltage regulation mode in bidirectional range and the limitations. Also modelling the DVR using ANFIS controller and modelling the DVR using TS Fuzzy like PI controller. Simulation results for both adaptive controllers were compared with the conventional PI controller. The software used was Mat lab/Simulink.

Chapter Five, Conclusions & Future Works, this part gives the finishes of this work and gives the recommendations for future works.

2. VOLTAGE REGULATION

The DVR gives three stages controllable voltage, whose vector (tremendousness and edge) adds to the source voltage to reestablish the stack voltage to pre-compounding (hang and swell), Static Series Compensator besides named Dynamic Voltage Restorer (DVR), where related between the source and weight as appeared in figure 2.1 [11]. Voltage list, which is a transient decreasing in rms voltage degree in the extent of 0.1 to 0.9 pu, is considered as the most serious issue of force quality. It is normally realized by issues in power structures or by the start of significant selection motors. It happens more much of the time than some other power quality wonder does.

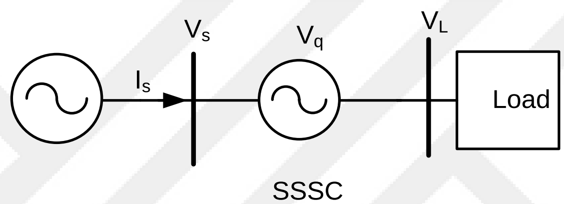


Figure 2.1: The Schematic Diagram of DVR System

In this manner, the misfortune came about because of voltage list issue for a client at the heap end is enormous. Swell is characterized as an expansion in rms voltage or current at the power recurrence, commonplace extents is somewhere in the range of 1.1 and 1.8 pu. Swell size is likewise portrayed by its residual voltage for lengths from 0.5 cycles to 1 min [12]. The meaning of droop and swell appeared in figure 2.2.

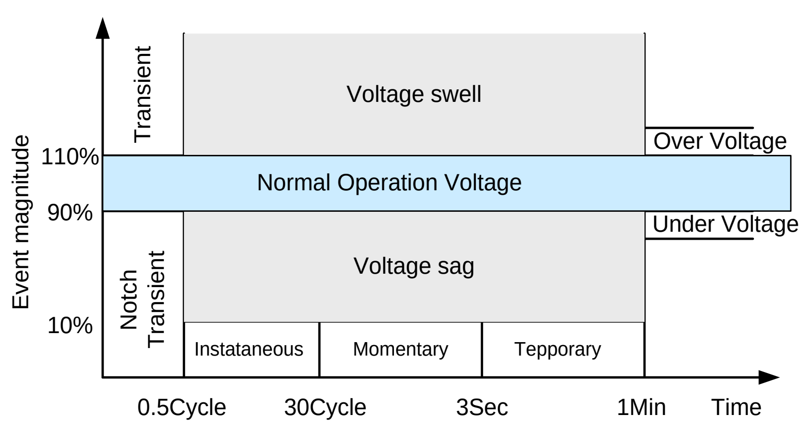


Figure 2.2: The voltage swell, normal operation voltage of different magnitude.

We deduce the following techniques:

1. Before-Sag Reimbursement
2. In-stage Reimbursement
3. Least Energy Reimbursement [13].

These tactics control are shown in figure 2.3A, B and C.

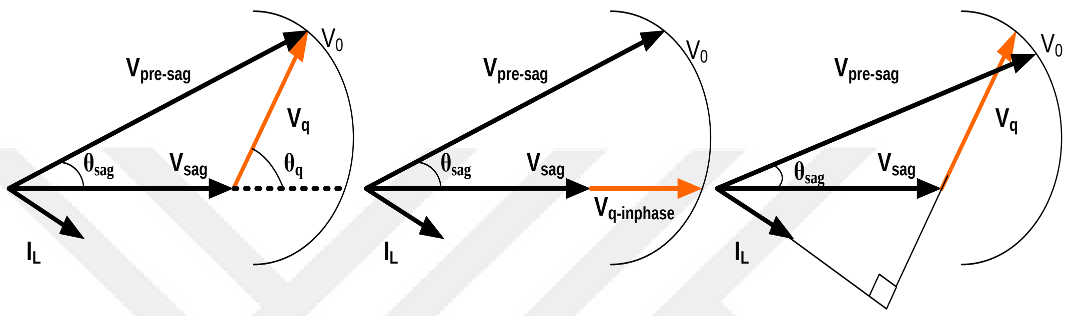


Figure 2.3: Three stages of control techniques and approaches.

2.1 PRE-SAG REIMBURSEMENT

The supply voltage is continually sought after and the heap voltage is repaid to the pre-hang condition. This procedure results in (about) undisturbed weight voltage, in any case, by and large, requires a higher rating of the DVR. Before a hang happens, (VS = VL). The voltage drape results in a drop in the criticalness of the supply voltage to Vsag showed up in figure 2.3A. The stage edge of the supply besides may move. The DVR blends a voltage Vq with a definitive target that the heap voltage (Vl = Vs + Vq) stays at pre-list voltage V0 (both in degree and stage). It is guaranteed that a few loads are touchy to organize hops and it is basic to make up for both the stage skips and the voltage hangs [14].

2.2 IN-STAGE REIMBURSEMENT

The voltage implanted Vq by the DVR is constantly in stage with the supply voltage paying little regard to the store current and the pre-hang voltage (Vo) as showed up in figure 2.3B. This control framework results in the base estimation of the injected voltage (measure). For weights which are not sensitive to the stage bounces, this control philosophy results [15].

2.3 MINIMUM ENERGY REIMBURSEMENT

The third stage is the base vitality infusion by limiting the dynamic power provided by the compensator. This can be gotten by infused voltage (Vq) in quadrature with the heap current. To raise the voltage at the heap transport, the voltage infused by the DVR is capacitive and VL drives VS as appeared in figure 2.3C. Execution of the base vitality pay requires the estimation of the heap current phase notwithstanding the supply voltage. At the point when (Vq) is in quadrature with the heap current, DVR supplies just receptive power [16]. In this examination, the DVR for voltage guideline dependent on in-stage/hostile to stage compensator was actualized to repay the heap voltage at droop/swell unsettling influence conditions. The subtleties of the control configuration will have examined in section 3.4.

2.4 IMPROVEMENT OF VOLTAGE STABILITY USING DVR

Voltage dependability characterizes as the capacity of a powerful framework to keep up the worthy voltage at all transports under typical working conditions and subsequent to being exposed to a possibility. Voltage strength is a nearby marvel, yet its results may have a broad effect, where a neighborhood voltage breakdown can and leads to a far-reaching breakdown of the power framework [17]. Normal for intrigue is the connections between communicated power (P) and receiving end voltage (V). The traditional form of this relationship PV curve obtained through steady-state analysis shown in figure 2.24. The power (MW) exchange is intended to show expanding load in a piece of the framework. Explicit transport must be chosen for observing and PV bend is plotted. As observed from the figure at the "knee" of the PV bend, voltage drops quickly with an expansion in MW exchange. The impacts of DVR appeared in the red line in figure 2.4, where the voltage security upgrade. Actualities gadgets, are utilized for voltage solidness improvement and expanding load capacity edge. DVR can improve the voltage stability by injection the controllable voltage in-phase with phase voltage of the controllable bus [18].

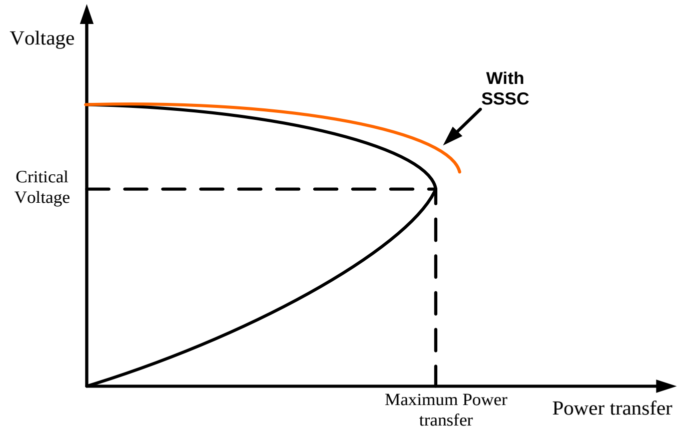


Figure 2.4: Power-Voltage Characteristic

2.5 SUMMARY

This chapter summarized the definition, construction, and modes of operation of DVR. The voltage regulation adopted the in-phase/anti-phase compensator mode. Next chapter presents the use of momentary power theory to implement them and also the control types for DVR.

3. DVR BASED MOMENTARY POWER THEORY AND CONTROL

In this chapter, the main theories of momentary voltage measurements have been presented, The DVR based on p-q theory for voltage regulation has been presented. The last section includes the design of DVR controllers with various types which are ANFIS and TS Fuzzy like PI controllers.

3.1 THEORY OF INSTANTANEOUS POWER

In 1983, Akagi et al. have proposed a theory utilizing quick estimations known as; "The Generalized Theory of the Momentary Reactive Power in Three-Phase Circuits or p-q hypothesis [19]. It depends on immediate qualities in three-stage control frameworks with or without unbiased, and is substantial for consistent state or transient activities, just as for nonexclusive voltage and current waveforms. The p-q hypothesis comprises of a logarithmic change (Clarke Transformation) of the three-stage voltages and flows from a-b-c directions to αβ0 facilitates. The p-q hypothesis manages each of the three stages in the meantime, as a solidarity framework, this unique in relation to the next customary power speculations, that regards the three-stage framework as three single-stage circuits, thusly this hypothesis dependably considers the three stages together, not as superposition or whole of three single-circuits. The p-q hypothesis gives an effective and adaptable reason for structuring the control techniques and executing them as controllers for power stream control and power conditioners dependent on power gadgets [20].

3.2. CLARKE TRANSFORMATION

The αβ0 change or the Clarke change the three-stage voltage in the abc stages, va(t), vb(t) and vc(t) into the quick voltages on the αβ0-tomahawks which are meant as: vα, vβ and v0. The Clarke change of the three phase voltage can be given as:

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{3.4}$$

Similar, three-phase generic line current:

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{3.5}$$

And the inverse transformations for voltage and current are (inverse Clarck transformation)

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} \tag{3.6}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \tag{3.7}$$

One favored perspective of applying the αβ0 change is to disengage zero-movement partitions from the abc-sort out parts. The α and β tomahawks make no obligation to zero-course of action parts. No zero-social event current exists in a three-mastermind, three-wire structure so that i0 can be shed from the above conditions, consequently accomplishing improvement. In case v0 and i0 can be abstained from the change arranges, the Clarke changes for voltage and current advanced toward getting to be:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{3.8}$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{3.9}$$

and their inverse Clarke transformation becomes:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \tag{3.10}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3.11}$$

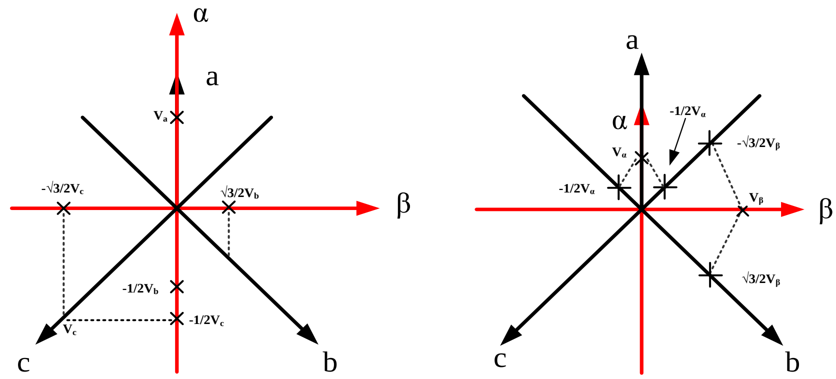
The graphical difference in eq 3.9 and eq 3.10 are showed up in figure 3.2. The snappy estimations of voltages and line streams suggested the abc stationary tomahawks can be changed into the αβ stationary, or a different way. The a, b and c coordinate are determined and moved by 2π/3 rad from each other while the α and β tomahawks are symmetrical, and the α turn is in line to the hub.

The momentary voltage vector can be characterized by the α- and β- voltage components as:

$$\mathrm{v} = \mathrm{v}_\alpha + j\mathrm{v}_\beta \tag{3.12}$$

Similarly, the momentary current vector becomes:

$$i = i_\alpha + j i_\beta \tag{3.13}$$



(a) (b)

Figure 3.1: Graphical Representations. (a) abc to αβ (b) αβ to abc

The momentary vectors in figure 3.1, can be spoken to in an unpredictable plane, where the genuine hub is the α pivot and the fanciful hub is the β hub of the Clarke change. It ought to be noticed that the voltage and current vectors characterized above are capacities of time, and they comprise of the Clarke segments of the momentary stage voltage and line current in a three-stage framework the vector chart in α hub and β pivot is aperies in figure 3.2.

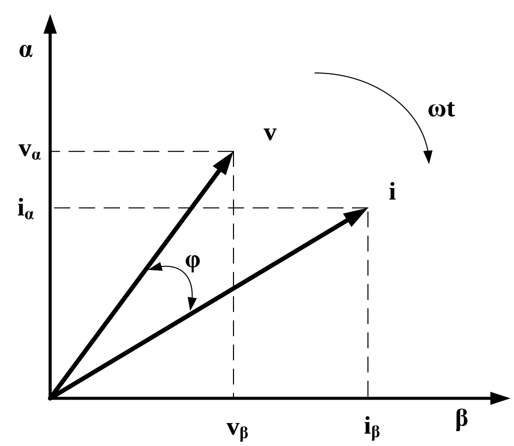


Figure 3.2: Vector Diagram of Voltage and Current on αβ Reference Frames

3.3 ACTIVE AND REACTIVE POWERS CALCULATIONS

The p-q hypothesis was portrayed in three-arrange structure with/without unbiased. Three sorts of brief forces are depicted which are; the smart zero-social affair control P_0, the brief special power p, and the blazing open power q, were portrayed from the quick stage voltage and line streams on the αβ0 rotate as:

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \tag{3.14}$$

Utilizing the expedient vectors of voltage and current which are showed up in figure 3.3, the short multifaceted power is delineated as the consequence of the voltage vector and the conjugate current vector i*, which can be to some degree awesome power:

$$s=v.i^*\underbrace{=(v_\alpha+jv_\beta)(i_\alpha}_{p}-ji_\beta)= \underbrace{(i_\alpha v_\alpha+v_\beta i_\beta}_{q})+j\,(v_\beta i_\alpha-v_\alpha i_\beta) \tag{3.15}$$

The dynamic and responsive power can be introduced in the structure is as shown:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3.16}$$

From eq 3.16 the momentary active and reactive powers can be rewrite:

$$p = v_\alpha i_\alpha + v_\beta i_\beta \tag{3.17}$$

$$q = v_\alpha i_\beta - v_\beta i_\alpha \tag{3.18}$$

These two forces (p and q) in eq 3.17 and eq 3.18, have steady qualities and superposition of wavering segments. The dynamic and responsive forces can be isolated into two parts:

$$p = \bar{p} + \tilde{p} \tag{3.19}$$

$$q = \underbrace{\bar{q}}_{\text{Average power}} + \underbrace{\tilde{q}}_{\text{oscillating power}} \tag{3.20}$$

Where:

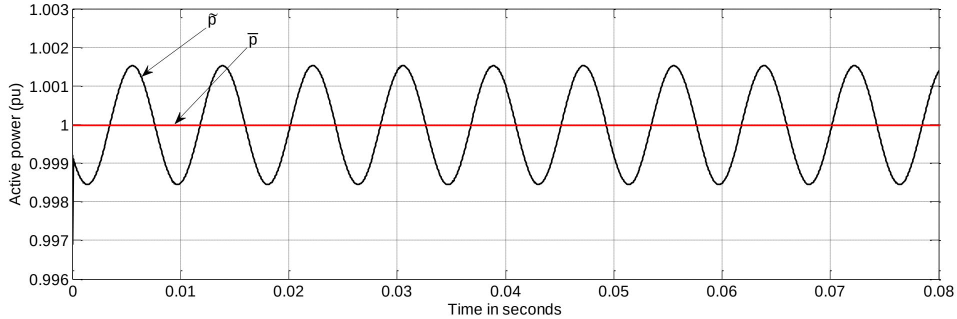
$\bar{p}$: Is the ordinary estimation of the quick unique power it identifies with the imperativeness per time unit that is traded from the power source to the store, in a reasonable way, through the a-b-c masterminds and proportional to the regard given in eq3.3.

$\tilde{p}$: Is the wavering estimation of the prompt unique power it is the centrality per time unit that is traded between the power source and the stack, through the a-b-c orchestrates. This part produced using consonant and unbalance segment of the heap current.

$\bar{q}$: Is the run of the mill estimation of the brief open power is indistinguishable to the typical responsive power (q = 3V I sin φ).

$\tilde{q}$: Is the wavering estimation of brief responsive power q and which does not induce any traded or exchange of essentialness between the power source and the store. Furthermore, as in $\tilde{p}$ this part conveyed from symphonious and unbalance fragment of the stack current [21].

The two bits of dynamic and responsive areas are appeared in figure 3.3 By utilizing the channel framework, the parts $\bar{p}$ and $\tilde{p}$ can be detached. Where low pass channel takes out the wavering segment $\tilde{p}$, while high pass channel disposes of the conventional part $\bar{p}$. a similar thing for nothing between $\bar{q}$ and $\tilde{q}$,figure 3.4 .



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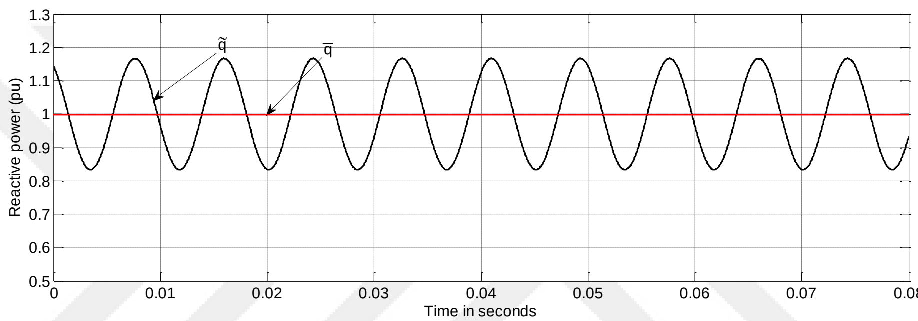


(b)

Figure. 3.3: Two Parts of Powers (a) Active Power (P) (b) Reactive Power (Q)

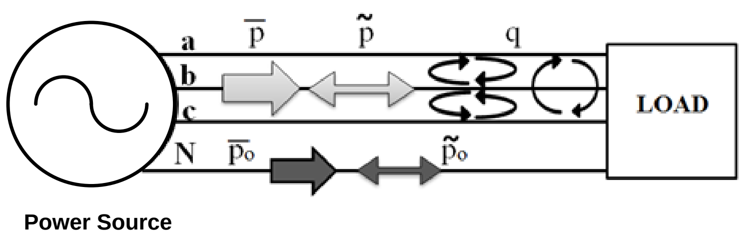


Figure 3.4: P-Q Theory Power Components in abc System

From the above discussion, it's clear that p-q theory has advantages in comparing with the two other theories and thus can be listed as [22]:

- It depends on momentary qualities, permitting phenomenal unique reaction.
- Simplest and less time for calculation powers compared with the two theories abc and d-q.
- P-q theory needs one transformation (Clarke transformation), where, d-q theory needs two transformations and, the abc theory needs to calculate the rms value of voltage and current.

- It needs six-samples to calculate active and reactive power, while d-q and abc theories need additional phase angle calculations.
- It is the best of the two theories to identify two types of components, where, in p-q theory the powers can be separated into two components average and oscillating, where average use in power flow control design while the oscillating use in active filters design [23-24].
- It can be connected to any three-stage framework adjusted or lopsided with or without sounds contains in the two voltages and flows.

From this discussion, the p-q theory has been adopted in this work to design the DVR for power flow control and voltage regulation.

Also there is a correspondence between momentary aggregated values and two voltages $v_\alpha \ and \ v_\beta$ in α-β coordination where:

$$v_\Sigma = \sqrt{v_a^2 + v_b^2 + v_c^2} = \sqrt{v_\alpha^2 + v_\beta^2 + v_0^2} \tag{3.21}$$

3.4 DVR BASED ON P-Q THEORY FOR VOLTAGE REGULATION

Using the concept of momentary power theory, DVR can be designed for voltage regulation, the injected voltage is made the reference signal of phase voltage as mentioned in section 2.6. After taken 3 samples instantaneously from the phase voltage of the controlled bus shown in figure 3.8, the two voltages $v_\alpha \ and \ v_\beta$ are determined by using Clarke transformation in eq 3.9, then the aggregated voltage calculated using eq 3.25. Wherev_Σ , is a constant value and equal to the rms value of the line-to-line voltage, to get the rms phase voltage the aggregated voltage is divided by square root of three. This momentary voltage is continuously compared with reference voltage where the reference voltage is the voltage bus at normal operation condition v_{ref}. The error signal Δv is calculated (the compensated voltage), where:

$$\Delta v = v_{ref} - v_\Sigma \tag{3.26}$$

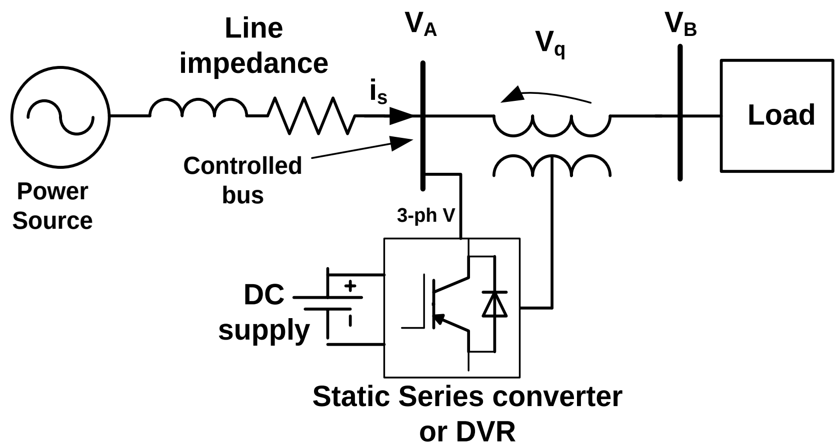


Figure 3.5: The DVR representation for voltages load and line impedance.

The error signals Δv can serve as input variables to the controllers. The output of the controller is the modulation index input to the SPWM. The angle ψ, will be 0^0 or 180^0 with the phase voltage depending on the sign of the error signal Δv in eq 3.26. The block diagram of DVR for voltage regulation based on momentary power theory shown in figure 3.6.

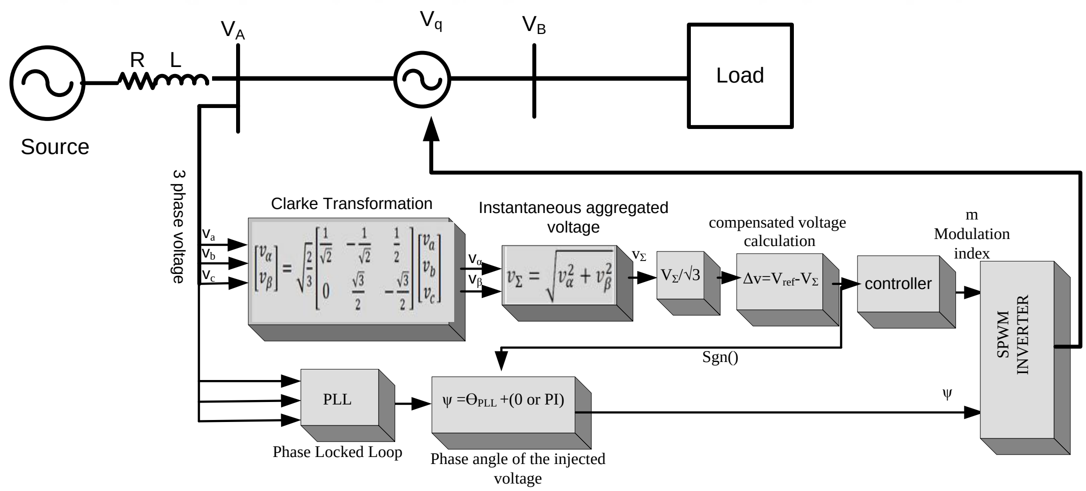


Figure 3.6: Block Diagram of DVR for Voltage Regulation Based on Momentary Power Theory

The Sinusoidal Pulse Width Modulation technique SPWM was used in the two operation modes of the DVR. The voltages v_{ca}, v_{cb} and v_{cc} in eq 3.24 are hree-phase sinusoidal which have a displacement of 120^o phase between each other. These voltages are the reference of modulating signal waves, and having variable amplitude from 0 to 1and the frequency of 50Hz. The frequency of the modulated signal

specifies the inverter output voltage frequency, and should be the same as the a.c. system frequency (50 Hz). There are two control parameters that adjust the inverter output voltage, amplitude m (modulation index) to reference signal frequency (frequency ratio). The modulation index determines the width of the on-state pulses and therefore the r.m.s. value of the inverter output voltage and should be less than one to operate the inverter in the linear range [25].
In this work the modulation index is adjusted by varying the amplitude of the modulation signal while keeping the carrier amplitude fixed. Two types to determine the amplitude of the modulating signal or modulation index, by using eq 3.24 and 3.25. The phase angle of the inverter output voltage can be adjusted by phase shifting the modulating signal with respect to the carrier signal.
Also, the frequency ratio selected to satisfy the following requirements:
It can be an integer, to avoid sub-harmonics, It should be an odd number, to eliminate even order harmonics, it should be multiple of three, to eliminate the triple harmonics.
From the above discussion, it is clear that using SPWM will provide linear control of the output voltage, the amplitude of the inverter fundamental frequency varies linearly with the modulation index and the inverter output voltage is given by:

$$V_1 = m\frac{1}{2}V_{dc} \tag{3.27}$$

Where, m is the modulation index and V_{dc} the voltage of the dc source.

3.5 DVR CONTROLLER DESIGN

In figures 3.7 and 3.9, the controllers can be considered as the main part of the DVR for using in power flow mode or in voltage regulation mode. Two types of adaptive controllers were designed for reimbursement and to achieve the desired performance of the DVR operation modes.
These controllers are:

- Adaptive Neuro-Fuzzy Inference System (ANFIS).
- Takagi-Sugeno Fuzzy Like PI Controller (TS-Fuzzy).

First, the conventional PI controller has been designed to get the initial performance of DVR, and it was considered that the first step for designing Fuzzy like PI controller.

3.6 PI CONTROLLER

For a standard PI controller, the compensated powers control signals are obtained as follow:

$$p_c = (p_{ref} - p)(K_{pp} + \frac{K_{ip}}{S}) \quad (3.28)$$

$$q_c = (q_{ref} - q)(K_{pq} + \frac{K_{iq}}{S}) \quad (3.29)$$

Where, Kpp and Kpq are the relative addition for dynamic and responsive power individually, Kip and Kiq are the indispensable increase for dynamic and receptive power separately. The control parameters can be assessed utilizing Ziegler-Nichols technique, also the use of trial and error methods to tune these parameters to achieve the desired gains of the controllers [26] the block diagram of the controller is shown in figure 3.7.

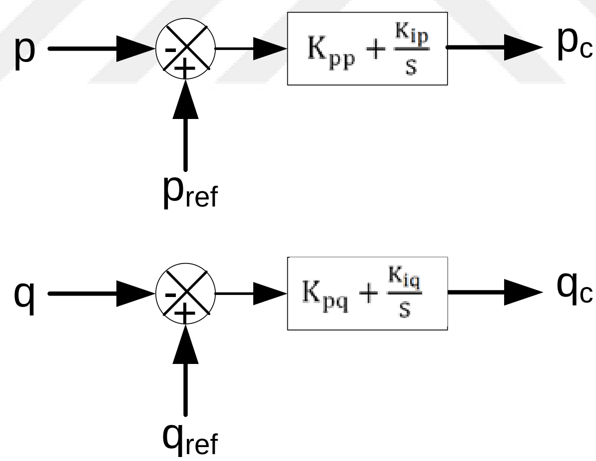


Figure 3.7: The Block Diagram of PI Controller

The burden of the traditional PI controller is that the fixed increases (Kpp, Kip, Kpq and Kiq) can't perform agreeably over a wide scope of intensity framework working conditions [27].

3.7 CONTROL SYSTEM BASED ON FUZZY LOGIC

The hypothesis of fuzzy rationale gives scientific solidarity to catch the vulnerabilities related to human psychological procedures, for example, considering and thinking. The fuzzy controller is being utilized is in an analysis control system. The strategy yield is differentiated and a reference and if there is a deviation, the fuzzy controller makes a move as demonstrated by the control technique as showed up in figure 3.8.

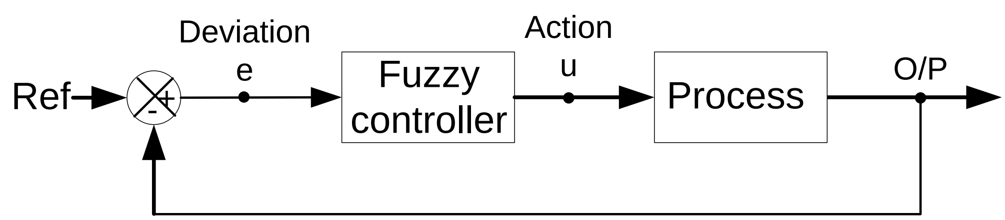


Figure 3.8: Fuzzy Logic Controller

The structure of fuzzy rationale control framework appeared in figure 3.9 The accompanying clarifies the parts of the fuzzy control framework:

Pre-processing:

The inputs are frequently hard or fresh estimations from estimating gear, rather etymological. A pre-processor conditions the estimations before they enter the controller.

Fuzzification:

Fuzzification changes over each bit of information to the level of participation in at least one enrollment capacities. In this investigation the triangle enrollment work with half covering has been spoken to the equal fuzzy contribution of the physical estimated amounts. This is appears in figure 3.10.

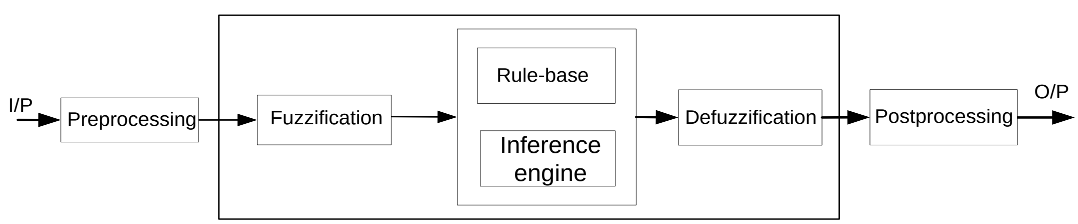


Figure 3.9: the Structure of Fuzzy Logic

Rule-base

The rules may utilize one or a few factors in the condition and the finish of each standard. For the most part, a semantic controller contains a lot of standards portrayed as: on the off chance that condition, at that point end.

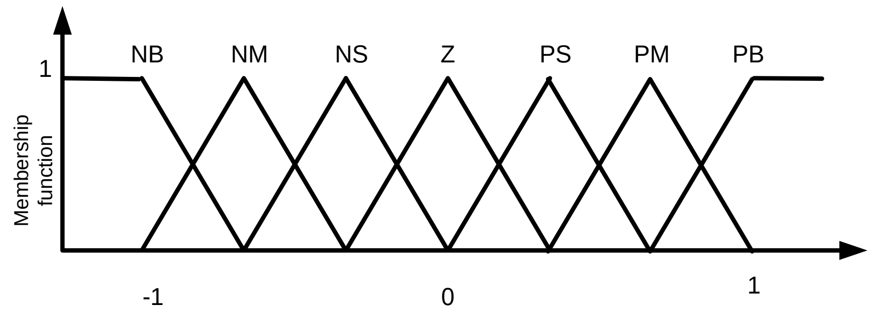


Figure 3.10: Ratios and membership functions of triangular standards of DVR.

Inference engine

The capacity of the induction motor is to register the general estimation of the present procedure states dependent on the commitment of each standard in the standard base.

Defuzzification

The defuzzifier convert the resulting output fuzzy set to a crisp value.

Post-processing

The output of the defuzzification process is usually defined on a standard universe. This must be scaled by the post-processing block to the engineering unites suitable for the system under study [28].

3.8 FUZZY LIKE PI CONTROLLER

The conventional PI controller described by equations 3.28 and 3.29 can be generalized as:

$$u = K_P e + K_I \int edt \qquad (3.30)$$

Where u is the control variable, e is the error signal for the corresponding controlled variable, K_P and K_I are the proportional and integral gains. The derivative of equation 3.30 is given:

$$\dot{u} = K_P \dot{e} + K_I e \qquad (3.31)$$

To drive a fuzzy logic that behaves like a PI controller, the algorithm defined by equation 3.31, then transferred into a set of fuzzy rules. Figure 3.11 shown the structure of fuzzy like PI controller.

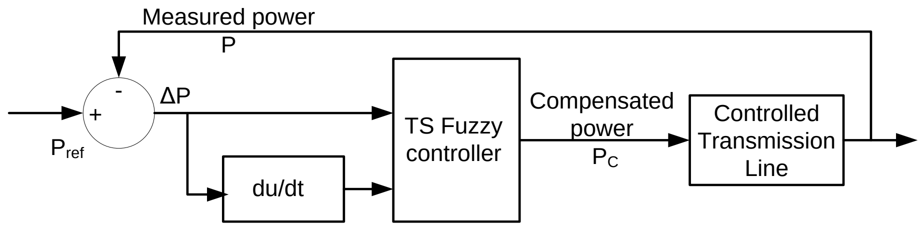


Figure 3.11: Fuzzy Like PI Controller Structure

In this investigation, the information signals are dynamic power and receptive power stream in the transmission line framework for arrangement inverter controller p and q. From condition 3.31. The mistake (e) and the difference in blunder (Δe) are utilized to create a two-input single-yield controller. The standard based, the phonetic depicted in table 3.1. The contributions of the blunder and the difference in mistake are fuzzified utilizing a term set of seven phonetic factors. Countless set parameters prompt an expansion of principles and consequently more calculation time.

Table 3.1: Rule-Base Linguistic for Fuzzy Like PI

e\Δe	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NB	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

3.9 ADAPTIVE NEURO-FUZZY CONTROL SYSTEM

The idea of fuzzy rationale can be fused into the neural system to generously decrease the estimation time and improving the execution. The subsequent cross breed framework is called fuzzy neural or Neuro-fuzzy. A neural system is utilized to tune the participation elements of the fuzzy framework. A versatile Neuro-fuzzy derivation framework (ANFIS) consolidates the fuzzy subjective methodology with the versatile capacities of the neural system. A control framework dependent on this can be prepared without noteworthy master information as contrasted and the standard fuzzy rationale framework [29].

In this research an Adaptive Neuro-Fuzzy Inference System (ANFIS) has been intended for the DVR controller. The preparation information is produced from the connection between the adjustment in the genuine and responsive power (Δp and Δq) that required in the framework and the comparing parts of the arrangement embedded voltage.

The design of ANFIS dependent on the main request Takagi-sugeno demonstrate is appeared in figure 3.15.

Rule ij: if x is A_i and y is B_j then $f_{ij} = g_{ij}x + h_{ij}y + r_{ij}$

Where, Ai and Bj speak to the etymological factors of related enrollment work (MF),

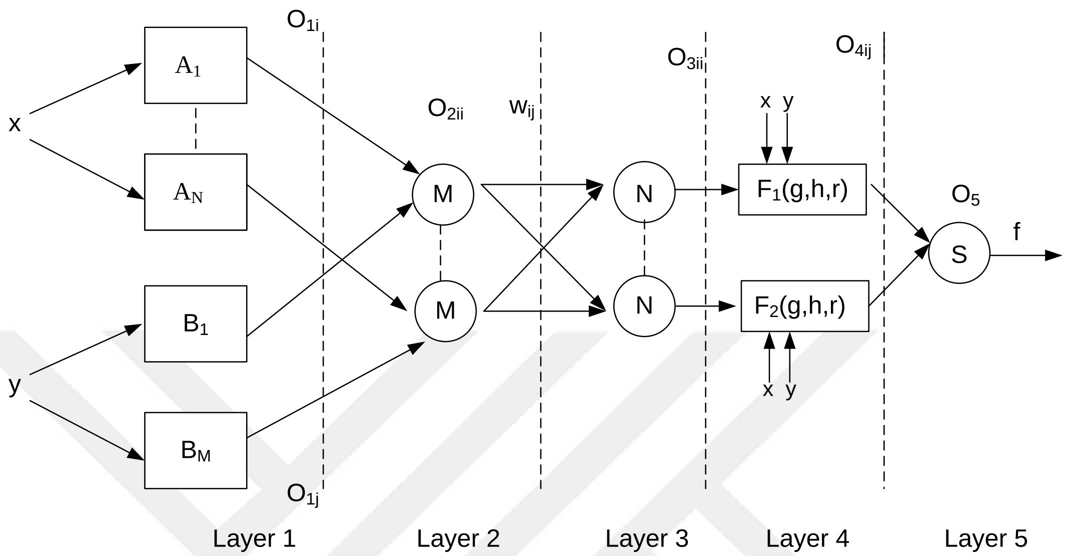
i= 1,2,… … ,N is the record number for the MF of the principal input,

j= 1,2,… … ,M is the record number for the MF of the second info and

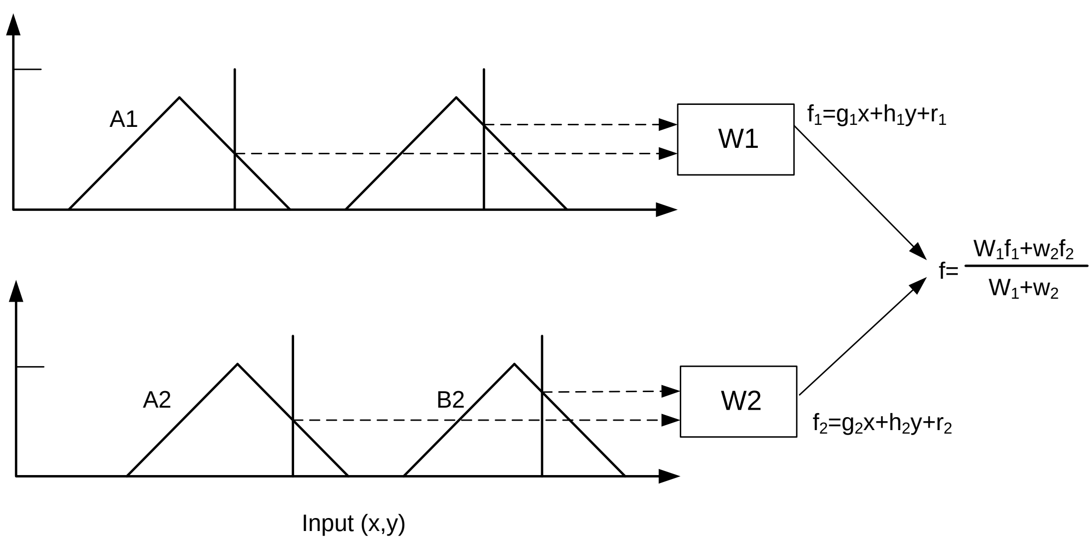
gij, hij and rij are the parameters of the yield participation capacity to be resolved amid the preparation arrange.

The ANFIS system consists of five layers is shown in figure 3.12, which represent the design steps of the fuzzy control system [30].

In this work, a hybrid learning strategy has been used which involves the gradient method to update the antecedent parameters {a, b, c} and least Square Estimate to identify the consequent parameters $\{g_{ij}, h_{ij}, r_{ij}\}$. At that point, in the regressive pass the mistake rate is engendered in reverse and the reason parameters are refreshed by slope drop while the ensuing parameters are fixed. Then, in the in reverse pass, the blunder rate is engendered in reverse and the reason parameters are refreshed by angle drop while the ensuing parameters are fixed. The cycle is rehashed until union inside a predefined mistake [31].



(a)



(b)

Figure 3.12: Architecture of ANFIS (A) ANFIS Structure (B) Takagi-Sugeno planned and analyzed fuzzy inference

3.10 TAKAGI-SUGENO TS FUZZY LIKE PI CONTROLLER

The intensive calculation time, gigantic information memory required and the expansive number of control rules are the point of confinement components of executing constant fuzzy controllers in Mamdani type fuzzy rationale controller [32]. On the other hand, Takagi-Sugeno TS Fuzzy controller type can give a wide extent of control gain assortment and can be use in either straight or non-direct coming about explanation of the fuzzy standard base. It gives a direct structure, diminishes the general computation time and offers a wide extent of control gain assortment reliant on its variable standard consequent [33]. In this sort the Adaptive Neuro-Fuzzy Inference System (ANFIS) was utilized to defeat the calculation time that in Mamdani type via preparing the information and to change the parameters of the yield participation capacities.

The hybrid learning methodology (Gradient Descent-GD) has been connected to recognize the system parameters.

In the next chapter the modeling and simulation of the DVR controller based on ANFIS and TS fuzzy were investigated.

3.11 SUMMARY

This chapter deals with p-q theory in details, It can be shown that the p-q theory has many advantages; Simple and less time in the calculation, needs one transformation (Clarke transformation) process. Also this chapter presents the two types of adaptive controllers were designed for DVR operations; ANFIS and TS Fuzzy like PI controllers. The adaptive controllers have an advantage over the conventional PI controllers that can be work over a wide range of voltage regulation.

In the next chapter, the simulation will validate the use of p-q theory for measuring and design for DVR operation and also a validation of the different types of controllers.

4. DVR MODELING AND SIMULATION

Modelling of the DVR based on p-q theory is a fundamental point of this study, and since the subject has many aspects to be presented, this chapter has been divided in to four sections which are;

Modelling of active, reactive power and voltage measurements using p-q theory, in this section the validation of using p-q theory for fast measuring active, reactive power and voltage in different conditions have been presented.

Two types of adaptive controllers have been designed; ANFIS and TS-Fuzzy and compared each type with conventional PI controller and between them for modified the performance of the DVR in a step change of active power in forward and reverse direction.

The DVR of voltage regulation control based on p-q theory has been designed and implemented by Matlab/Simulink. Depending on the maximum of the injected voltage the range of compensated of the controlled bus voltage in both directions has been identified.

4.1 MODELING OF P-Q THEORY FOR ACTIVE AND REACTIVE POWER MEASUREMENTS

The circuit diagram is presented in Figure 4.1. The system was divided into four parts. To change the load, three branches of loads for three-step change test and the fourth branch is implemented in case of transient test. The system has three subsystems which are; subsytem1, 2 and 3. To represent the three theories p-q, abc and d-q theories respectively, the models are shown in figures 4.2a, b and c. Using p-q theory, to measure active and reactive power, first the measured voltages and currents are transformed from a-b-c to α-β coordinates by Clark transformation as in eq 3.8 and eq 3.9 respectively, and then the momentary using eq 3.17 and eq 3.18 respectively.

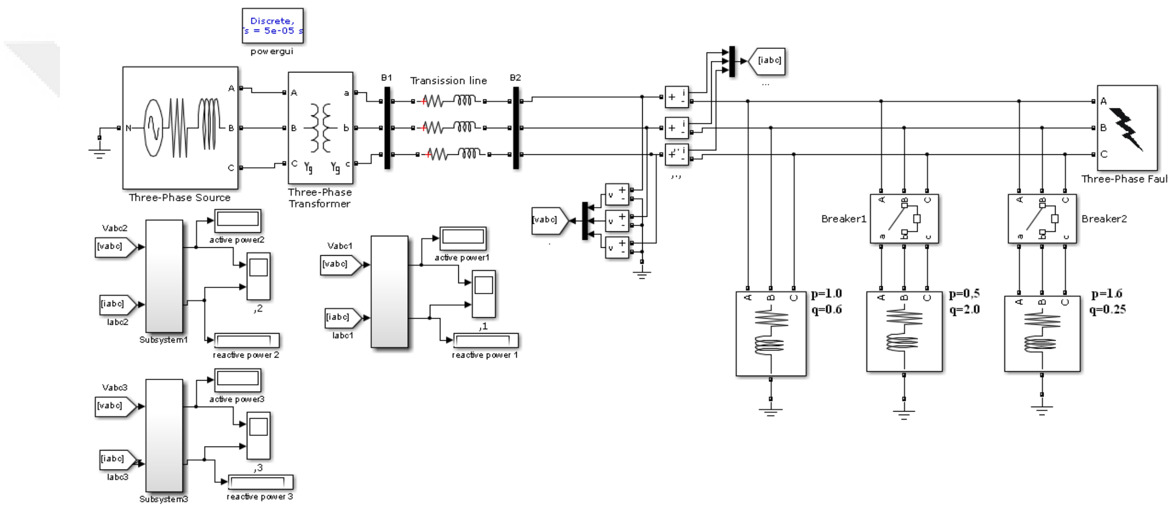
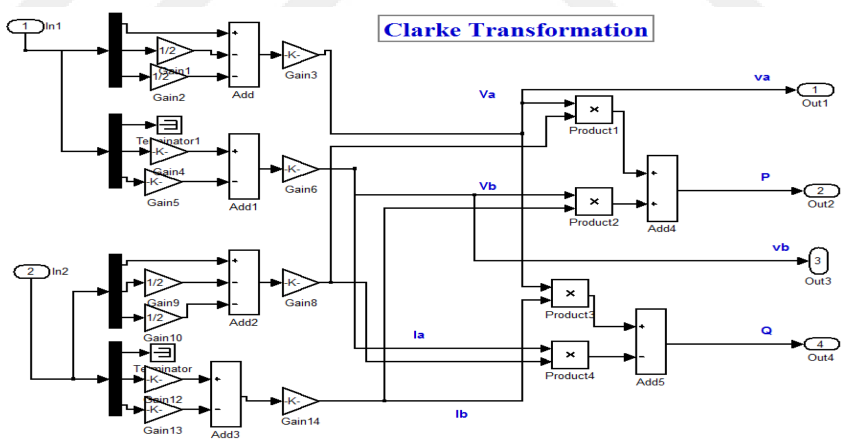


Figure 4.1: The Model for Testing P-Q Theory

4.2 SIMULATION RESULTS

For load step change tests, at t=0.17sec beaker 1 closed the load increased by p=0.5 pu and q=2.0 pu, and at t=0.34 sec breaker 2 closed and another value of load added as p=1.6 pu and q=0.25 pu. Figures 4.2a and b show the waveforms of V_α,V_β, I_α and I_β, the active and reactive power are shown in figure 4.2b. it is clear that the value of V_α and V_β at the rated values and with constant amplitude, I_α and I_β were changed if the load changes.



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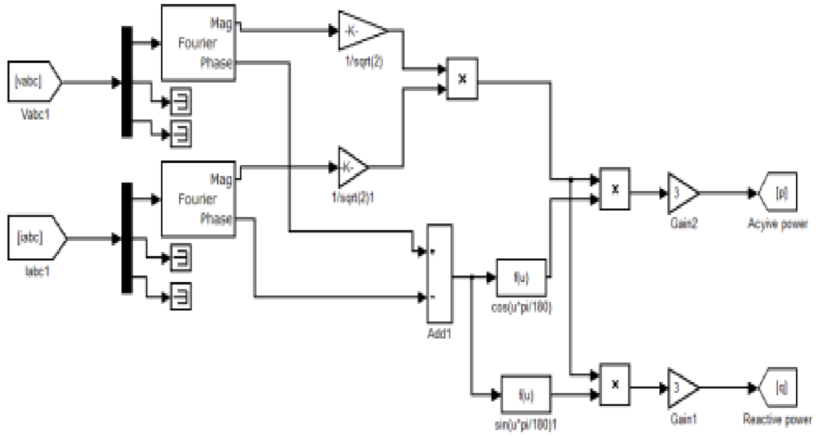
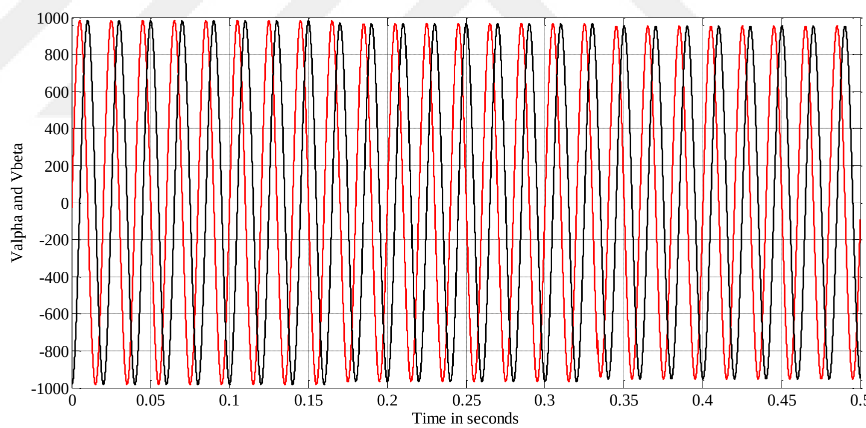


(b)

Figure 4.2: P-q Theory (a) Abc Theory (b) D-q Theory



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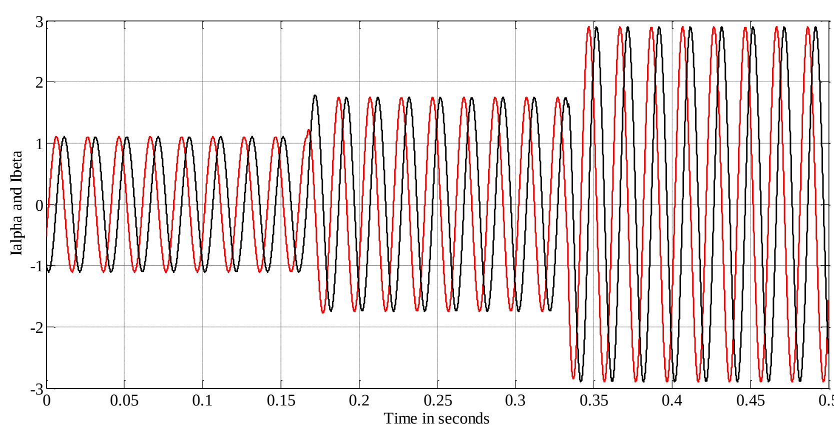

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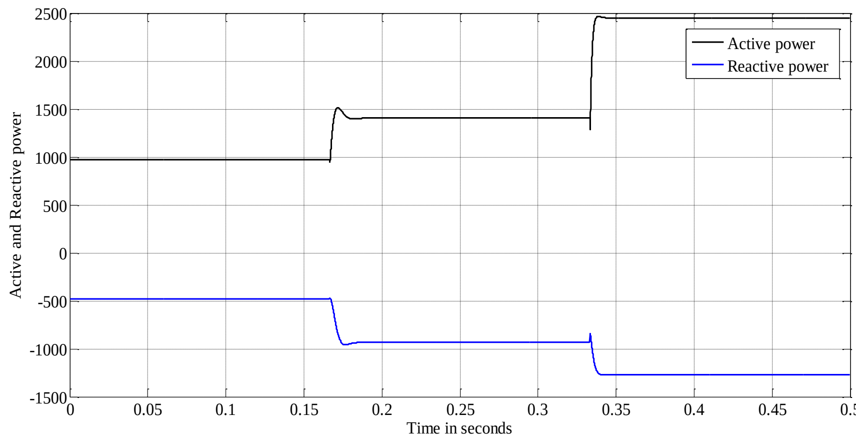
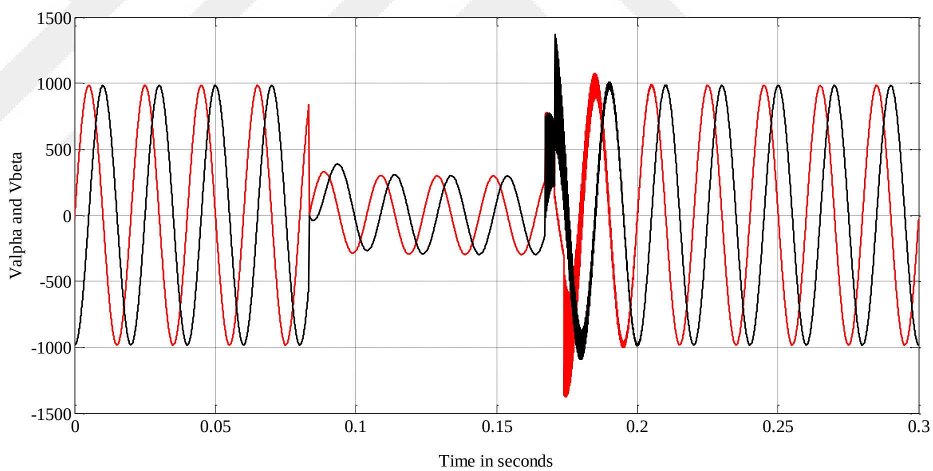


(c)

Figure 4.3: The Step Change of Active planned voltage and Reactive planned power (a) V_α and V_β (b) I_α and I_β (c) Momentary Active And Reactive Power



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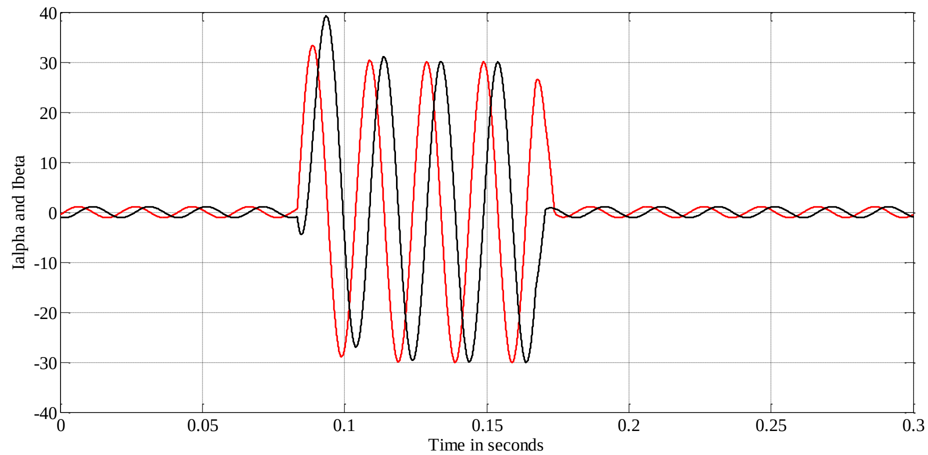
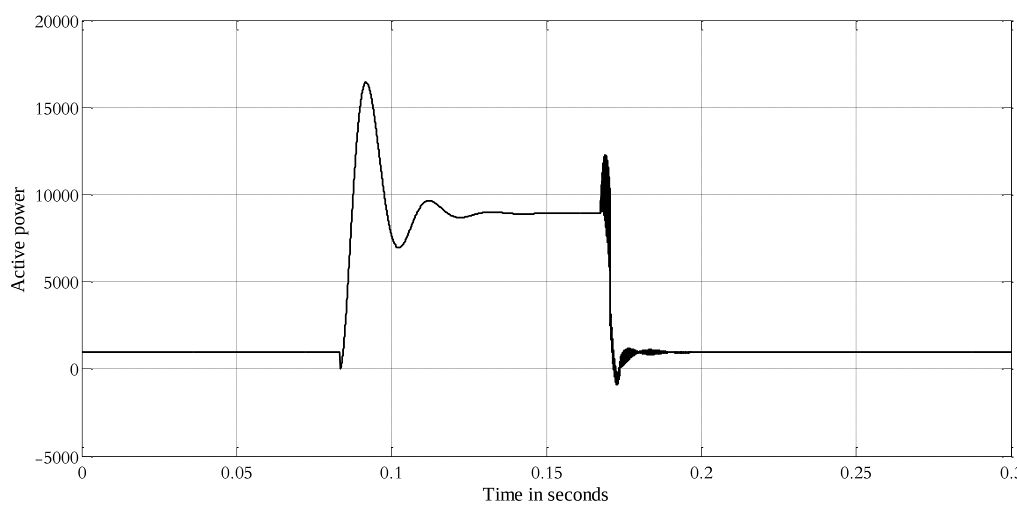


(b)

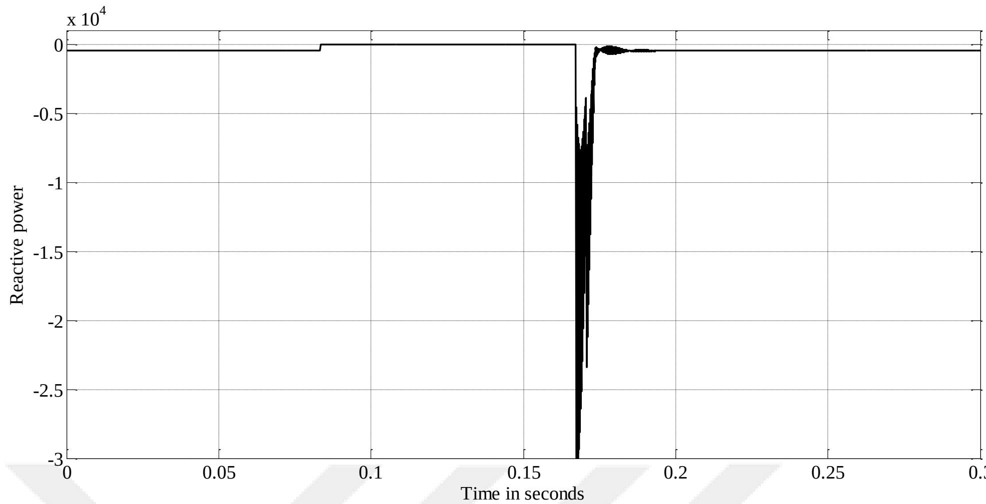
Figure 4.4: Quadrature Components at Fault Condition (a) V_α, V_β (b) I_α, I_β

From the results in figure 4.3c, power measured was constant values and equal to the average powers, so it can be used to control powers instead of the average measurements.

For test p-q theory in an abnormal condition, a three-phase fault (Line-Line-Line to Ground) was considered. This fault is made to occur for a period of 0.1sec and then cleared. Figure 4.4a and b show the waveforms of V_α, V_β, I_α and I_β the fault occurs at t=0.08 sec, the change is shown in figure 4.5.



(a)



(b)

Figure 4.5: Momentary Power Measurements at Fault Condition (a) Active Power (b) Reactive Power

Comparison of the response time between three methods for measuring the active power response was shown in figure 4.5. From figure 4.5b, it can be notice that the response time was less than 5msec (a quarter of cycle), where the other theories taking about 20msec.

4.3 MEASURING CIRCUIT:

There are 6 variables need to measure momentarily, the three-phase voltages and the three-phase line currents. By using Clarke Transformation which was shown in figure 4.2a, the active and reactive powers were calculated, then compared with the reference values of P_{ref} and Q_{ref} as will see in section 4.4.3. The compensated power P_c and Q_c (output from the controller), converted to $V_{c\alpha}$ and $V_{c\beta}$ using eq 3.23. By using Inverse Clarke Transformation these voltages converted to three sinusoidal voltages (V_{ac}, V_{bc}, V_{cc}), which are represent the magnitude (reference modulation signal). The block computation of magnitude is shown in figure 4.6.

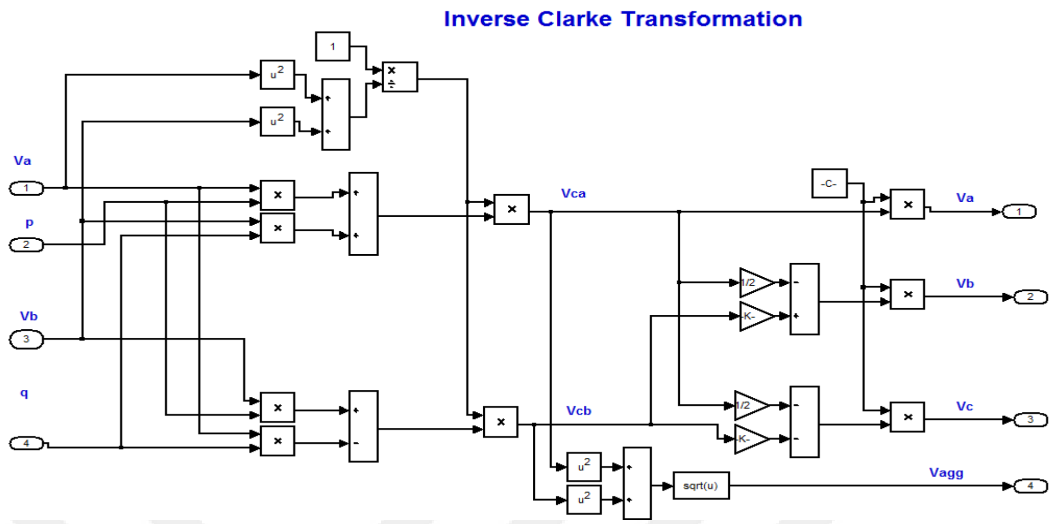


Figure 4.6: Inverse Clark Transformation

The phase angle of the injected voltage ψ obtained using eq 2.16. Figure 4.7 shows the computation block of the phase angle. From the figure, the

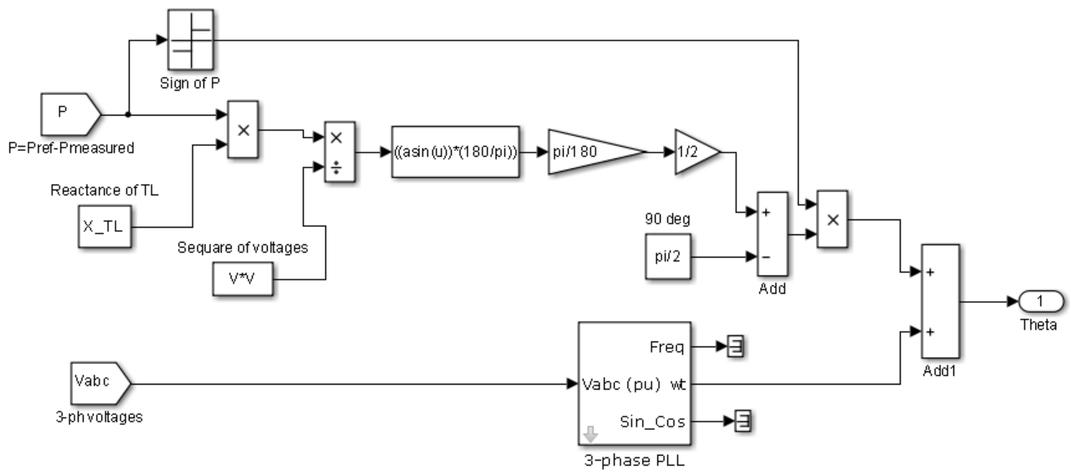


Figure 4.7: Phase Angle Computation Block

Phase locked loop (PLL) circuit was used to synchronize the injected voltage with the phase voltages. The sign of the injected angle depending on the error signal (ΔP) of eq 3.21. To get constant maximum power transfer the additional angle γ was calculated using eq 2.15.To generate the injected voltage, the inverter with the SPWM technique has been used. The carrier signal is a fixed signal with frequency modulation of 4500Hz. The SPWM inverter used with LC filter. The L-C filter was used at the output of the inverter with cut-off frequency 4500Hz shown in figure 4.8. The FFT analysis of the injected voltage is shown in figure 4.9.

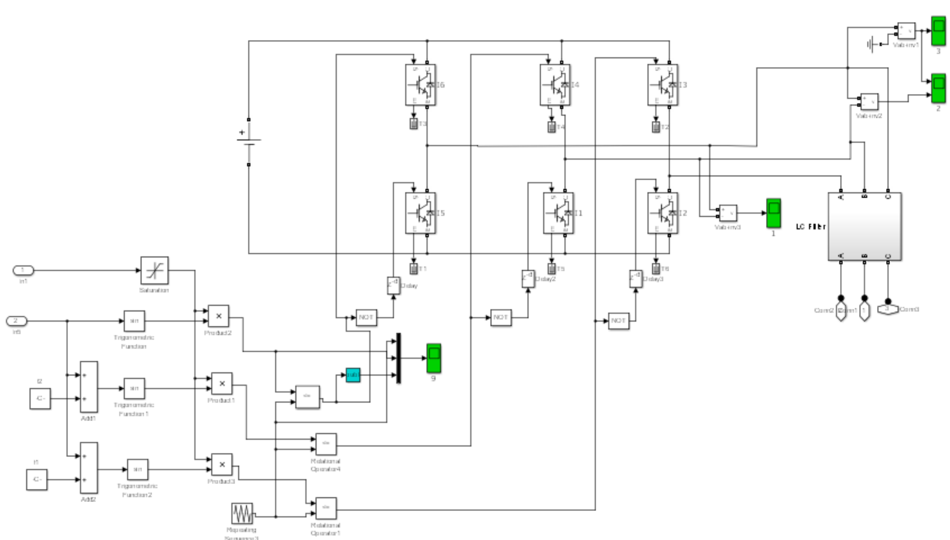


Figure 4.8: The Schematic Diagram of the SPWM Inverter

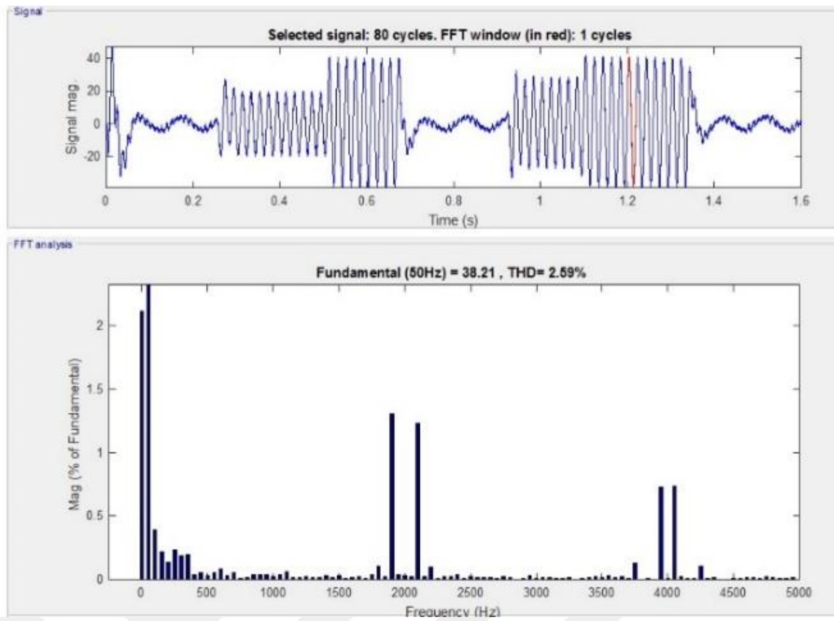


Figure 4.9: The FFT of the Phase Voltage after the LC Filter

To measure and regulate the power flow, the injected voltage was made in quadrature, this scheme will control the load angle. Figure 4.1 shows the phase voltage of the controlled bus and the injected voltage.

4.4 MODELING OF DVR IN VOLTAGE REGULATION MODE

The DVR has been modeLled for voltage regulation. The model was validateD to response to the common disturbances in the power system sag and swell. Figure 4.10 shows the model in Matlab/Simulink used in this case. To measure the phase voltage of the controlled bus V_1, the aggregated voltage v_Σ calculation was used (mentioned in section 3.4).

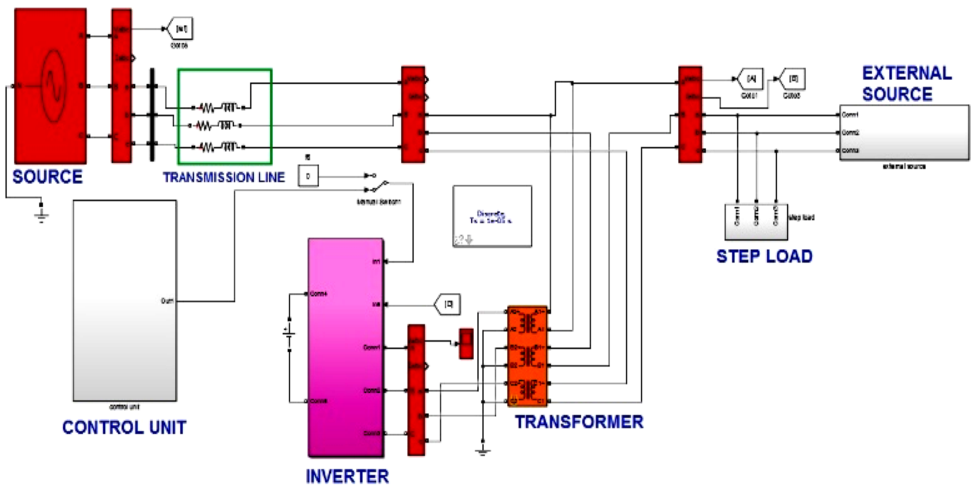
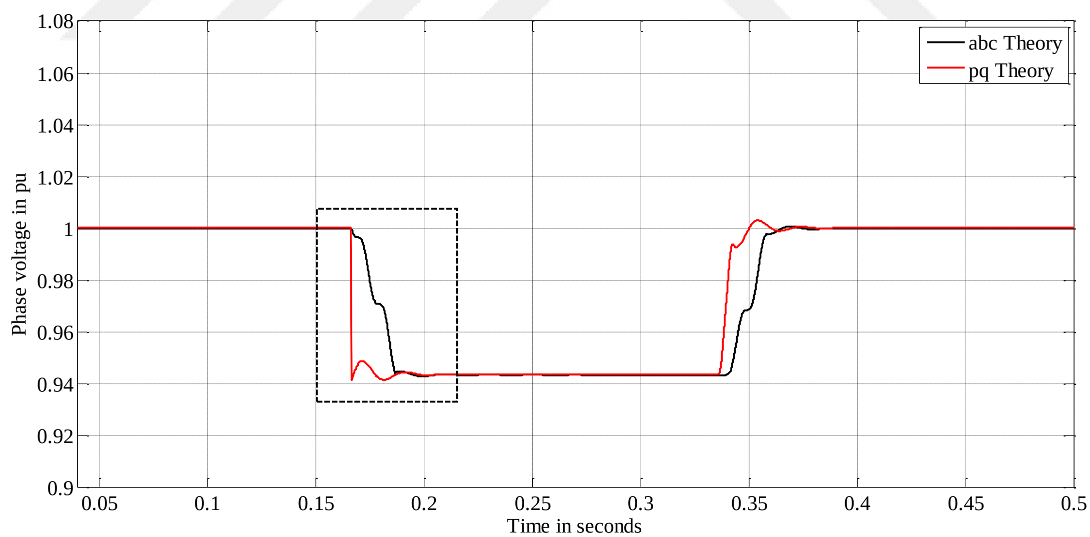
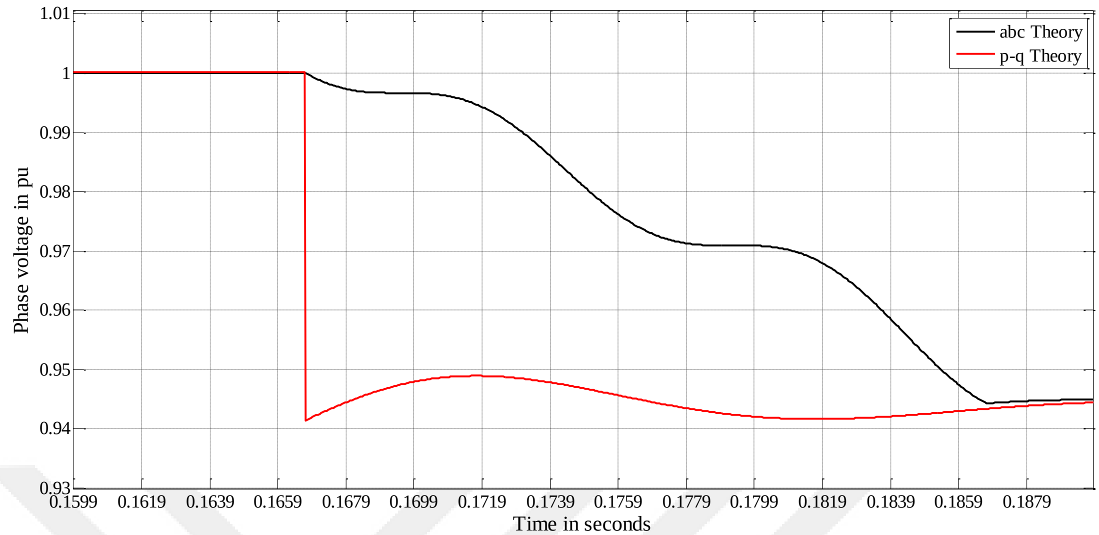


Figure 4.10: The Matlab/Simulink Model of DVR for Voltage Regulation

Figure 4.11 shows the time response of the p-q theory to measure the step change in the phase voltage, compared with abc theory (rms theory), the measuring time to the step change in voltage using pq theory takes less than 2msec compared with rms that takes about 20msec.



(a)



(b)

Figure 4.11: Step Change in Phase Voltage (a) P-q &rms Theories (b) Zooming in

The controller is the main part of the DVR in voltage control mode. TS Fuzzy like PI controller has been designed. The maximum injected voltage was 0.1 pu of the phase voltage in both directions (in-phase and anti-phase) to compensate for the bus voltage at sag and swell conditions. Each input variables to the fuzzy logic controller were split into 7 triangular membership functions, and a 49-control rule. The trained data for (e and Δe) of the phase voltage V_1 is shown in table 4.1. The information on the controller design shown in table 4.2.

Table 4.1: The faults and change of faults of the voltage.

e\Δe	-0.1	-0.0667	-0.033	0	0.033	0.0667	0.1
-0.1	-0.1	-0.1	-0.1	-0.1	-0.0667	-0.033	0
-0.0667	-0.1	-0.1	-0.1	-0.0667	-0.033	0	0.033
-0.033	-0.1	-0.1	-0.0667	-0.033	0	0.033	0.0667
0	-0.1	-0.0667	-0.033	0	0.033	0.0667	0.1
0.033	-0.0667	-0.033	0	0.033	0.0667	0.1	0.1
0.0667	-0.033	0	0.033	0.0667	0.1	0.1	0.1
0.1	0	0.033	0.0667	0.1	0.1	0.1	0.1

Table 4.2: TS Fuzzy Information for Voltage Regulation

Number of nodes	**131**
Number of linear parameters	**147**
Number of nonlinear parameters	**42**
Total number of parameters	**189**
Number of training data pairs	**49**
Number of fuzzy rules	**49**
Training error after 3 Epoch	**1.7247e-07**
Testing error	**0.033034**

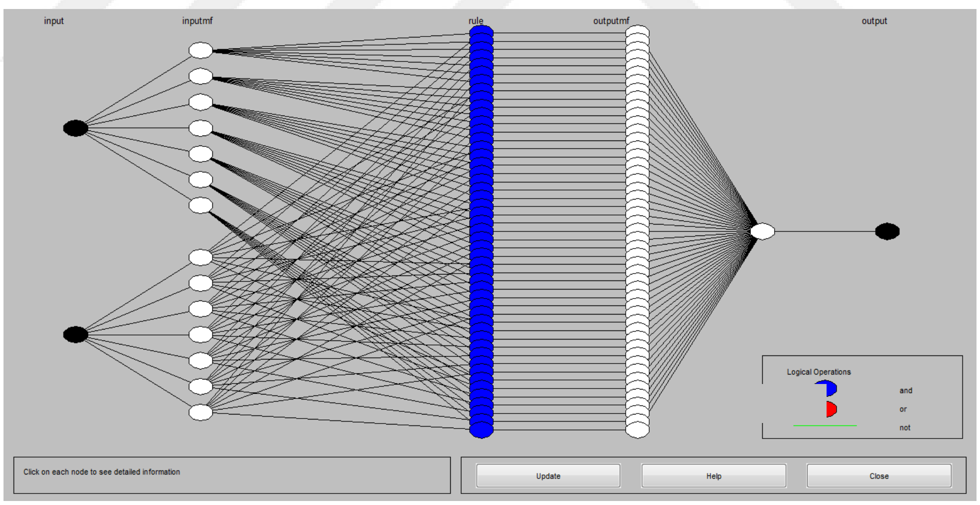


Figure 4.12: Model Structure of TS Fuzzy

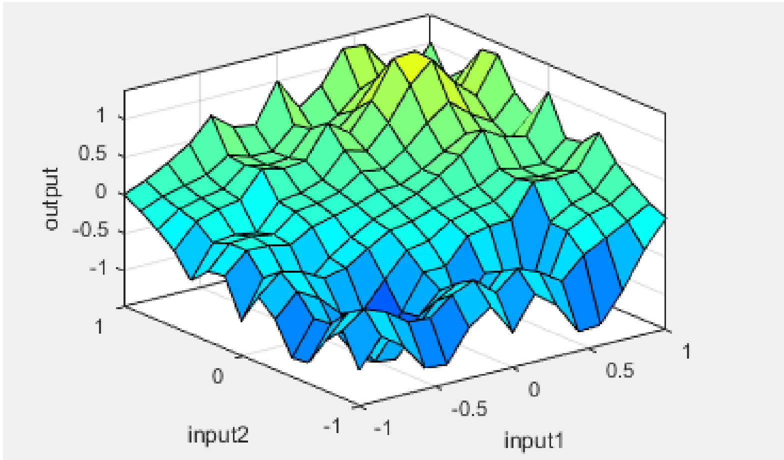


Figure 4.13: The Surface Structure of the TS Fuzzy

4.5 SIMULATION STUDY

Droop and swell unsettling influences have been produced to approve the DVR in voltage guideline mode, these aggravations were made in the control transport position (V1) in the Matlab demonstrate, the stage voltages were estimated when DVR (when infusion voltage), the scope of the DVR.

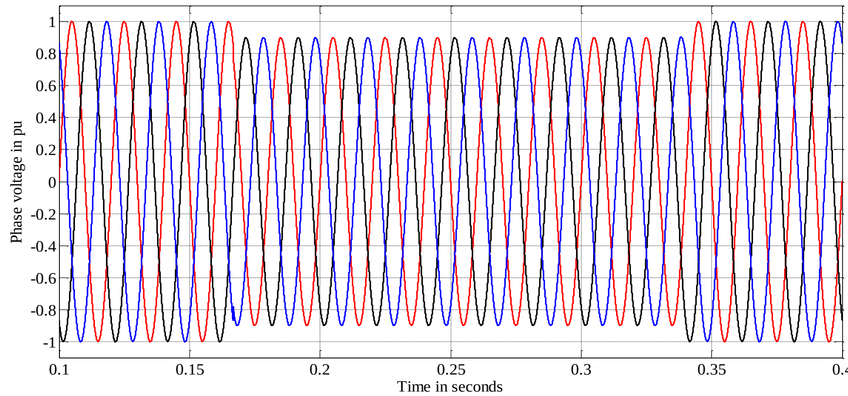
4.5.1 Sag Condition

A sudden increase in load change at V_1, this load decreases the voltage at sending end to about 0.9 of the normal operation value V_{ref}. This reduction was in the control region of DVR. In the sag test, the three-phase voltages after and before injection are shown in figure 4.14. The injected voltage was in-phase with phase voltage and at its maximum value of 0.1 pu of the reference voltage.

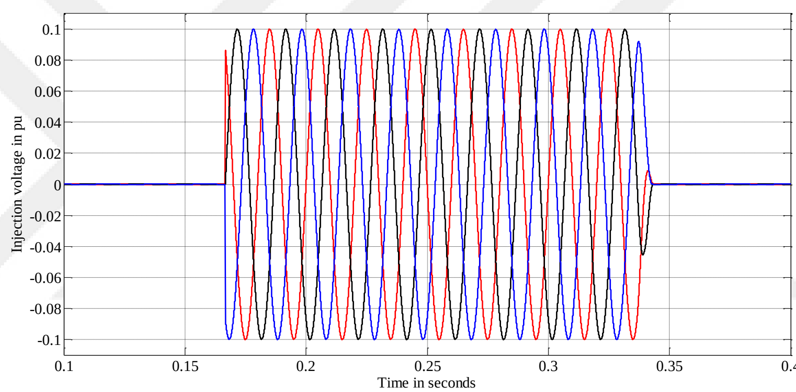
4.5.2 Swell Condition

As in sag condition, a sudden decrease in load change at the controlled bus (V_1), this decrease in loaded cause increase the voltage at the load to about 1.1 pu of the normal operation value V_{ref}. Figure 4.15 shows the three-phase voltages before and after injecting voltage, where the injected voltage was in anti-phase (180^0) with phase voltage and at its maximum value of 0.1 of the reference voltage the resultant voltage will be subtracted.

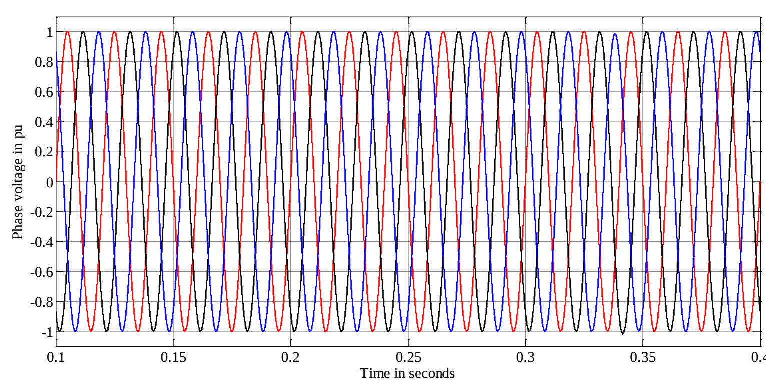
If the disturbance was greater than the control region, this means the drop of more than 10% of the reference value V_{ref}. The DVR will inject a compensated voltage at its maximum value, this will mitigate the drop in voltage as shown in figure 4.16.



(a)

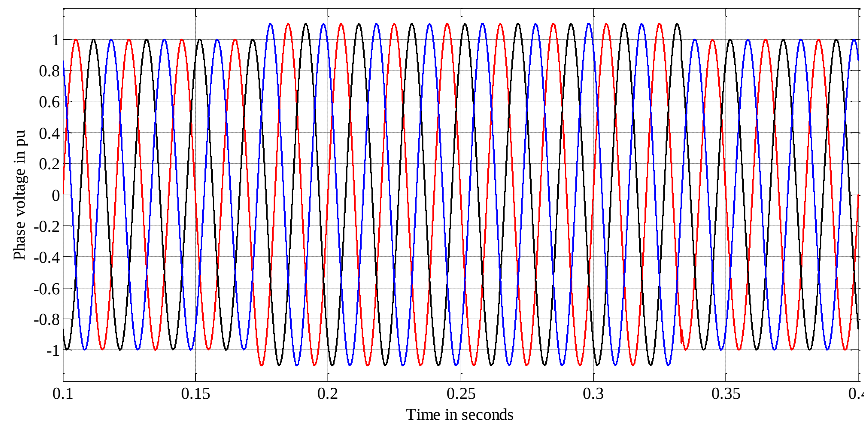


(b)

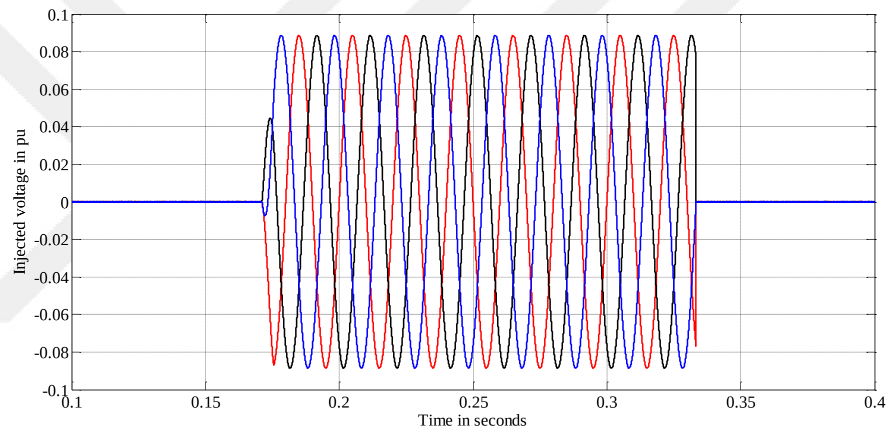


(c)

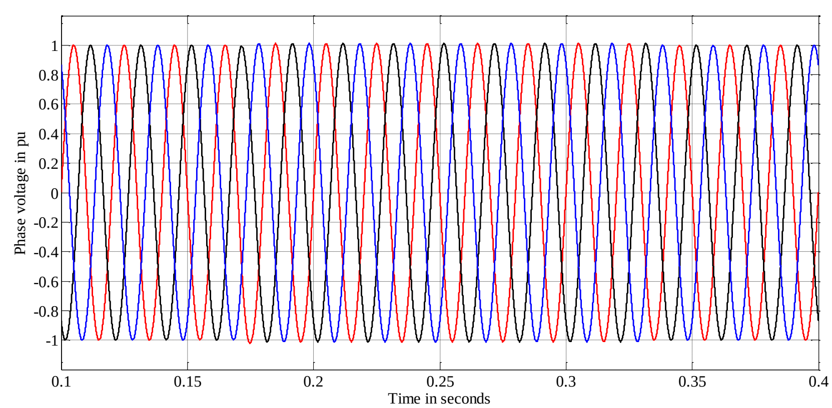
Figure 4.14: Three Phase Voltage of injected and planned multiple Controlled Bus in sag condition (a) Before Reimbursement (b) The Injected criteria for duration of Voltage (c) After Reimbursement



(a)



(b)



(c)

Figure 4.15: Three Phase Voltage of injected and planned multiple Controlled Bus (a) Before Reimbursement (b) The Injected criteria for duration of Voltage (c) After Reimbursement.

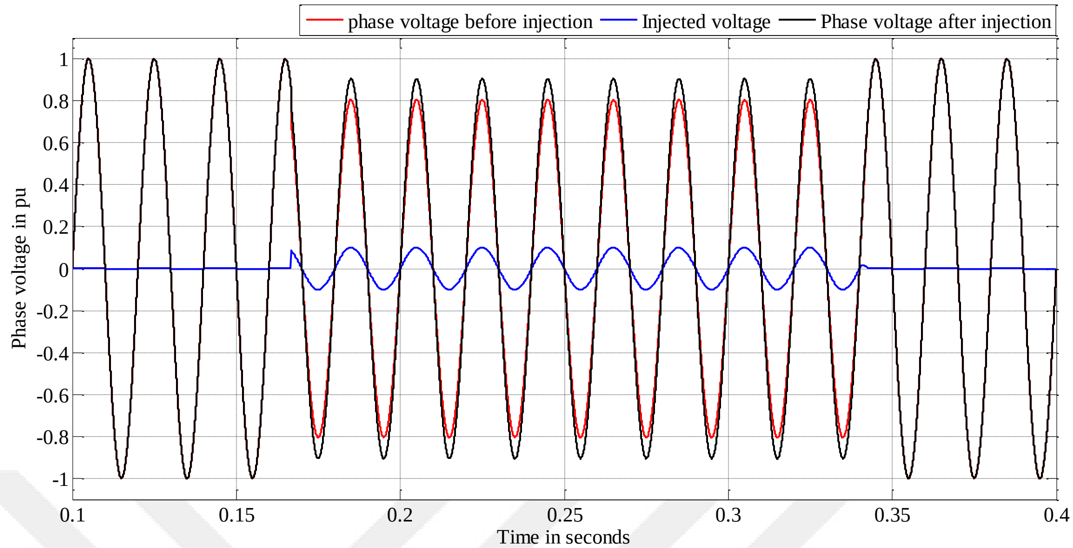


Figure 4.16: DVR Mitigate the Voltage Dip

4.6 VOLTAGE STABILITY ENHANCEMENT

From the results of the voltage reimbursement in both conditions sag and swell, the DVR can improve the voltage stability of the controllable bus. Figure 4.51 shows the phase voltage before and after injection voltage with increase the transfer power to the load (active power).

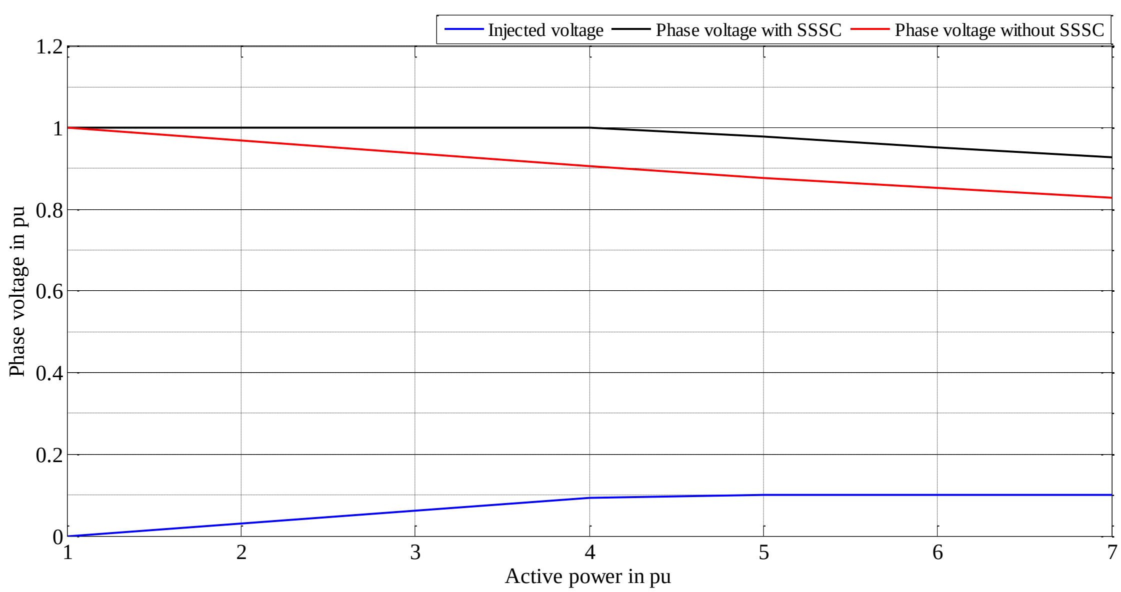


Figure 4.17: The Power-Voltage Characteristic with DVR

From figure 4.17, DVR continuous the process to compensating the drop of voltage until it reaches the boundary of the control region, in 4 pu active power load which is V_{qmax}=0.1 pu. After this point, the DVR will remain at its maximum injected voltage V_{qmax}.The stability margin increases in about 10%, and this will delay the voltage collapse point.

4.7 SUMMARY

In this chapter, the DVR for voltage regulation control mode has been analyzed planned current for this purpose and modelled using Matlab/Simulink. The control mode was based on p-q theory. The chapter includes three sections, the first section was to validate p-q theory for measuring active, reactive power and voltage. The results showed that p-q measuring time needed has less than 2 msec in measuring the voltage. The second section includes the DVR design based on p-q theory. The voltage regulation range of voltage control was ±10% of the V_{ref}. To get the best performance, TS Fuzzy was designed for DVR control. The PI controller has been used to compare the performance with the adaptive controller. The results show the adaptive controllers best than the conventional PI controller. TS Fuzzy was used for voltage regulation.

5. CONCLUSION

5.1 CONCLUSION

In this work, the DVR based on momentary power theory for voltage regulation has been designed, analyzed, and tested in simulation using Matlab/Simulink.. The momentary power theory has been used for fast measuring the main parameters in the power system; active power, reactive power and the voltages. This theory has been validated in simulation test, the results in showed the ability of this theory to measured active, reactive and voltage with very fast response time, the measure time of active and reactive power was less than 5msec (a quarter of the cycle), and in voltage the time took less than 2msec. Compared with another theory of measuring these components (p,q and v), like abc-theory (rms-theory) and d-q theory the simulation and practical results show that the p-q theory was the fastest theory in measuring.

The voltage regulation range of voltage control was ±10% of the V_{ref}. To get the best performance, TS Fuzzy was designed for DVR control. The PI controller has been used to compare the performance with the adaptive controller. The results show the adaptive controllers best than the conventional PI controller. TS Fuzzy was used for voltage determination.

The ranges of compensated voltage were ±10% of planned and analyzed this injected phase turned voltage, this injected voltage will increase or decrease the amplitude of the phase voltage for sag/swell conditions, also the system voltage stability margin increased by 10%.

The simulation has been performed in Matlab/Simulink, a 6-pulse inverter of the SPWM technique was used with a switching frequency of 4.5 KHz, the total harmonic distortion THD of the injected current and phase voltage after injected a 10% of the phase voltage were 0.88% and 1.3% respectively.

Suggestions for future works Investigate more cases in voltage regulation mode like faults condition and unbalance condition, and use active filters instead of passive filter to remove the harmonics.

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