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Comparison of Control Strategies of Wind Power Based Induction Motor Variable Displacement Pressure Compensated Pump

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ABSTRACT

This examination researches the use of the sliding mode controller (SMC) for induction motor drive variable displacement pressure compensated pump (VDPC) system controlled by a secluded wind/loading unit. The variable-speed wind turbine (WT) is proposed to drive a permanent magnet synchronous generator (PMSG) which, strengthen a putting away energy unit and remain single dynamic load. Energyloading systems are required for control adjust quality in detachedwind control systems. At first, the all-encompassing model of the whole system is accomplished, including the PMSG, the uncontrolled rectifier, the buck converter, the capacity system, induction machine and the VDPC pump. The power consumed by the associated loads can be viably conveyed and provided by the proposed WT and energyloading systems, subject to sliding mode control. The primary reasons for existing are to supply 220 V/50 Hz through a three-stage inverter and alter the IM speed also, VDPC pump current rate. The execution of the proposed system is contrasted and the neural system control and the traditional PID control. The recreation comes about demonstrate that the proposed system with the SMC and ANFIS system controllers has great execution and great expectation of the electrical parameter waveforms contrasted and the case of the customary PID controller.

Keywords: Sliding Mode Controller (SMC), permanent magnet synchronous generator (PMSG), variable-displacement pressure compensated pump (VDPC), Artificial Neuro-Fuzzy Inference System(ANFIS)

I. INTRODUCTION

The expanding rate of consumption of regular energy sources has offered ascend to expanded accentuation on sustainable power sources such as wind, small scale hydro, biogas, and so forth. Remote territory wind control age units are nowadays getting to be noticeably famous in disconnected locales [1– 3]. Be that as it may, the plan and operation of such systems are trying because of the nonappearance of the principle electric systems. Also, these sorts age units are generally described by systems having low damping, low X/R proportions, and absence of reactive control which may cause unforeseen voltage and frequency outings outside their coveted desired points [3]. Moreover, existing of capacity system in separated age system ensures providing loads with required power. If there should arise an occurrence of wind energy transformation (WEC) systems, numerous generators can be utilized to actualize these systems.

The fundamental preferred standpoint of permanent magnet synchronous generators (PMSG) is that they needn't bother with any outside excitation current. A noteworthy money saving advantage in utilizing the PMSG is the way that a diode connect rectifier might be utilized at the generator terminals since no outside excitation current is required. The system topology utilized in this paper depends on a PMSG associated through an uncontrolled extension rectifier and a buck converter to the DC-interface for little and medium power ranges [4].

Because of the very factor characteristic of the wind, utilizing of aenergy capacity device, for example, a battery can essentially enhance the unwavering quality of a little independent windsystems. Blending a appropriate energyloadingsystem in conjunction with a wind-generator wipes out the voltage changes and can expand the dependability of the power provided to the loads [5]. In the separated generation controlsystem, wind age control system might be worked to build the wind control changed over into electrical power. The caught control is provided to the load specifically, the contrast between the wind control age and client utilization being coordinated to or provided by the battery energyloadingdevice associated by means of the power electronic interface [6].

The lead– corrosive batteries (LABs) are the overwhelming energyloading innovation, with their preferences of low value, high unit voltage, stable execution, and extensive variety of working temperature [7, 8]. Henceforth, the LABs constitute an energizing test, as major segments in the improvement of the remainsinglewindenergysystems [9]. The variable structure control technique utilizing the sliding mode has been centered aroundmany investigations and research for the control of the wind age systems [10–14]. The sliding mode control can offer numerous great properties, for example, great execution against un-displayed flow, inhumanity to parameter varieties, outer unsettling influence dismissal and quick powerful reaction [15]. These favorable circumstances of the sliding mode controller (SMC) might be utilized in the speed control of the inductionmotor (IM). In this investigation, controller plan and recreation of disengaged age unit including variable speed wind-putting away energysystem controlling dynamic load in view of sliding mode control are proposed. The power required by the IM-variable-displacementpressurecompensated pump (VDPC) pump load can be viably conveyed and provided by the proposed control age systems utilizing the proposed sliding mode control. The proposed age system and the provided dynamic load with the proposed controller has been tried through advance changes in wind speed, valve opening rate and IM rotor speed. Reenactment comes about demonstrate that there better following of the motor speed, pump pressureand pump currentrate notwithstanding a superior forecast of the electrical parameter waveforms.

II. SYSTEM CONFIGURATION

Figure 1 demonstrates a detached wind age unit drive dynamic load. The exhibited dynamic load is an IM drive VDPC pump system. The IM is nourished from the wind/loading power age unit through DC-interface. The DC-connect principally comprises of two sections. The initial one is the generator side AC/DC converter which incorporates an uncontrolled AC/DC rectifier and buck DC/DC converter. The second part incorporates the load side DC/AC converter which is comprised of three stage PWM inverter. A capacity unit (LAB) is associated with the DC-side of the DC-interface. In this investigation, the battery has both the two said capacities. (I) To help in keeping up the DC-connect voltage consistent in the event of wind or potentially load varieties. (ii) To supply loads all through quiet periods or if there should be an occurrence of low wind control age. As a rule, the terminal voltage of a PMSG, which driven by wind turbine (WT) and nourishes segregated load depend for the most part on the rotor

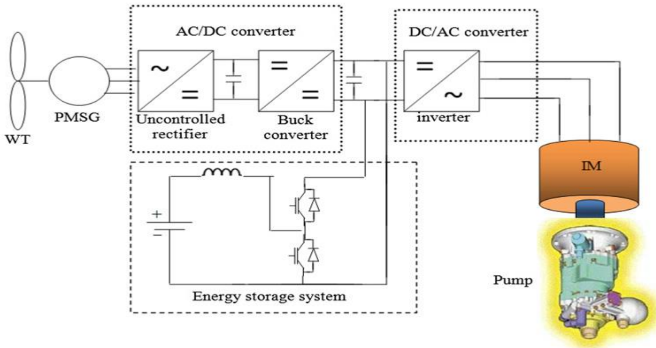

Figure 1. Schematic diagram of the proposed stand-alone WEC system

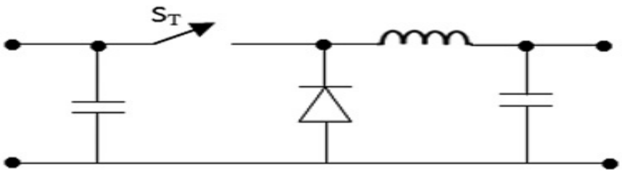

Figure 2. Buck-converter circuit diagram

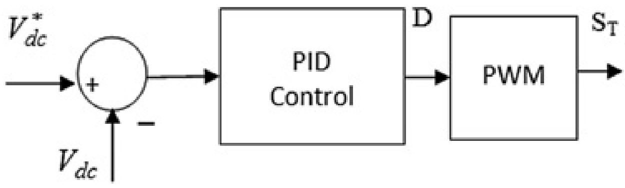

Figure 3. Buck-converter controller block diagram

speed and the load current. In this way, if the load on the generator changes, or/and, if the wind speed changes, there is a possibility that the terminal voltage and frequency will change. This is offensive to sensitiveloads.

In this work, there are three fundamental control circles. The first is the DC-interface control circle which is capable to keep up the buck DC/ DC converter output voltage at its coveted an incentive by controlling its obligation proportion in light of PID control. The second one is the battery charge/release controller which additionally in view of PID controller. Where, the battery will charge when the wind age control is more than the power required by the load and the other way around when the wind control is not as much as the required load control, the battery will release. The third control circle is capable to control the DC/ Air conditioning inverter output voltage so that the IM rotational speed meet its wanted an incentive if there should be an occurrence of wind speed varieties or/and load varieties (pump valve opening %) in view of sliding mode control. Since the proposed system is profoundly non-straight, particularly the dynamic load system (IM pump system), it is proposed to utilize a non-straight control as SMC.

III. SYSTEM MATHEMATICAL MODELLING

The model of the entire WEC system can be divided into severalinterconnected subsystem models as shown in Figure **1**. Thesesubsystems are the WT, the PMSG, the rechargeable battery, theAC–DC converter, the DC–AC inverter, the IM and the VDPCpump.

3.1 WT model

The WT output power Pt, which is a function of the blade angle β,the mechanical angular rotor speed ωt, tip speed ratio l and thewind speed Vw, can be expressed as [16]

$$Pt= \frac{1}{2}rACp(\lambda,\beta)V^3_w \tag{1}$$

where ρ is the air density, and A is the swept area by the blades [16]and Cp is the power coefficient of the wind speed, which can beexpressed as [16]

$$Cp(\lambda,\beta) = (0.44 - 0.0167b)\sin\frac{\pi(\lambda-3)}{15-0.3\beta} - 0.00184(l - 3)\beta \tag{2}$$

3.2 PMSG modelling

The dynamic model of the PMSG has been described in the d-q rotorframe as follows [17]

$$\frac{d}{dt}i_{sd}= \frac{1}{L}(-Rsi_{sd}+ pw_rL_{sq}i_{sq}- V_{sd}) \tag{3}$$

$$\frac{d}{dt}isq= \frac{1}{L}(-Rsi_{sq}+ pvr(L_{sd}i_{sd}+ \lambda pm) - V_{sq}) \tag{4}$$

where R is the stator resistance, isd is the d-axis current, isq is theq-axis current, L is the stator inductance. Stator inductance in d-and q-axis are assumed to be equal (Ld=Lq=L). d/dt is thedifferential operator; Pg is the pole pairs of the PMSG, ωristhe mechanical rotor speed, lm is the flux linkage generated fromthe permanent magnet material, the magnetic flux lm is a constantthat depends on the material used for the realisation of the magnets.

The mechanical dynamics are given by:

$$\frac{d}{dt}w_r= \frac{1}{J}(Tm- T^g_e)\_ \tag{5}$$

where Tm is the mechanical torque applied to the WT shaft and canbe expressed as [16]: (see (6))

Tg

e is the PMSG electromagnetic torque, which can be expressed as

$$T^g_e= \frac{3}{2}\frac{Pg}{2}\ \lambda m\ i_q \tag{7}$$

3.3 IM mathematical model

The stator and rotor voltage equations of an IM in a synchronousframe can be expressed as follows [18]

$$\frac{dids}{dt} = \frac{1}{\sigma Ls}[- (ra+ L^2_mr_r/L^2_r)i_{ds}+ws\,\sigma\, L_si_{qs}+L_mr_r/Lr\ \lambda\ dt+ (Lm/Lr)w_ml_{qr}+ v_{ds}] \tag{8}$$

$$\frac{diqs}{dt} = \frac{1}{\sigma Ls}[-w_s\ \sigma\ L_si_{ds}-(r_s+ L^2_mr_r/L^2_r)iqs+(L_mr_r/L_r)\lambda qr-(L_m/L_r)v_m\lambda dr+ v_{qs}] \tag{9}$$

$$\frac{d\lambda dt}{dt}= -r_r//Lr\ \lambda dr+ (v_s-v_m)\ \lambda q_r+ L_mr_rL_ri_{ds} \tag{10}$$

$$dlqrdt= -r_rL_r\ \lambda_{qr}- (v_s-v_m)\ \lambda dr+ L_mr_rL_ri_{qs} \tag{11}$$

$$dw_m/dt= 1/J(T^m_e- Tl- f\ w_m) \tag{12}$$

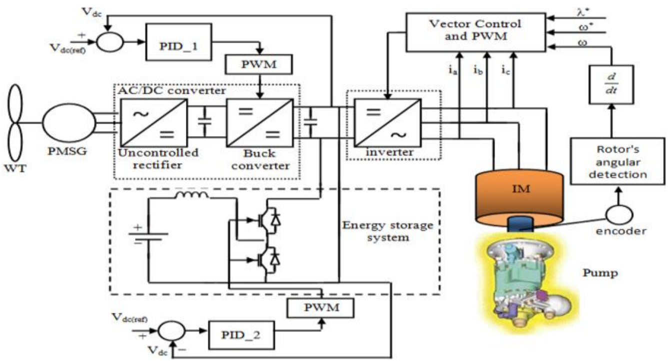

Figure 4. Schematic diagram of the stand-alone wind/battery storage energy conversion unit with proposed control system

whereTme is the electromagnetic torque developed by the IM

$$T^m_e= n_p(L_m/L_r)\ \lambda_{dr}i_{qs}- \lambda_{qr}\ i_{ds}),\ \sigma= 1 - L^2_mL_sL_rS \tag{13}$$

3.4 VDPC pump

In this investigation, it is proposed to utilize a general VDPC pump. The pump tries to keep up its preset pressure at its outlet by controlling its conveyance current as per the system needs. On the off chance that

pressuredifferential over the pump is not as much as the setting pressure, the pump outputs its most extreme conveyance rectified for inward leakage. After the pressure setting has been acquired, the outputcurrent is controlled to keep up the preset pressure by changing the pump's relocation. The VDPC pump is represented to with the accompanying
conditions [19].

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After the pressure setting has been gotten, the outputcurrent is controlled to keep up the preset pressure by changing the pump's relocation. The VDPC pump is represented to with the accompanying conditions [19]

$q = D_p w_p - k_{leak} P$ (14)

$T = D_p P / h_{mech}$ (15)

$D_p = D_{max}$ for $P \leq Pset$

$D_{max} - K(P - P_{set})$ for $P_{set} \leq P \leq P_{max}$

0 for $P \geq Pmax$ (16)

$P_{max} = P_{set} + P_{reg}$ (17)

$K = D_{max} P_{max} - P_{set}$ (18)

$k_{leak} = k_{HP} / v\rho$ (19)

$k_{HP} = (D_{max} w_{nom}(1 - hv) v_{nomr}) / P_{max} - P_{set}$ (20)

$P_p = P_p - P_T$ (21)

3.5 Embedded uncontrolled rectifier model

As the wind speed varies with time, the PMSG rotor speed differs as well. Henceforth, the AC outputvoltage of the PMSG fluctuates in frequency and size, which is inadmissible for some purchasers what's more, loads. Subsequently, this variable AC voltage is amended to DC voltage at that point changed over to controlled AC voltage again with consistent abundancy and frequency. In this investigation, an uncontrolled diode connect rectifier is utilized to change over the PMSG variable output voltage to a variable DC voltage. Assuming that the commutating edge and inductance are unimportant, the DC output voltage and current of the rectifier can be given as far as the rmsphasevoltage and current of the PMSG respectively, as [20, 21]

$VDC_{(rect.)} = 3\sqrt{3}V_g/\pi$ (22)

$IDC_{(rect.)} = (\pi/2\sqrt{3}) I_g(rms)$ (23)

3.6 DC–DC converter

In this study, the DC–DC converter is implemented using a buckconverter. The unidirectional buck converter achieves an interfacebetween the uncontrolled rectifier and the inverter to regulate thetransfer of power. The circuit diagram of the simple buckconverter and its proposed TS-fuzzy logic controller are shown inFigs. 2 and 3 respectively.The voltage and current relationships between the primary andsecondary sides are given by

$V_{rect}/V_{dc} = D$ (24)

$I_{rect}/I_{dc} = 1/D$ (25)

D is the duty cycle ratio of the converter.

3.7 Energy storage system

The energyloadingsystem is made out of a single stage, one arm, IGBT bidirectional inverter and a bank of LAB. The battery can supply the power gave to the load by the wind age system, when the wind speed is too low. The proportional electrical model of the LAB contains a controlled voltage source (Eb), associated in arrangement with the interior protection what's more, the LAB voltage (Vbat). It is realized that the Eb voltage
relies upon the charging state and the battery sort [8].

3.8 DC–AC converter and vector control

The energyloadingsystem is made out of a single stage, one arm, IGBT bidirectional inverter and a bank of LAB. The battery can supply the power gave to the load by the wind age system, when the wind speed is too low. The proportional electrical model of the LAB contains a controlled voltage source (Eb), associated in arrangement with the inward protection furthermore, the LAB voltage (Vbat). It is realized that the Eb voltage
relies upon the charging state and the battery sort [8].]

1.The developed torque Tm*e and flux l* should be obtained andthen the corresponding reference stator currents in d and q-axis i^*_{ds}andi^*_{qs} are obtained.

2. The angular position θ is then obtained and it used intransformation between synchronous and stationary referenceframes to achieve the desired stator current in d and q-axiscomponents.

3. Then, the gotten d and q-axis components of the stator current instationary reference frame is converted to the desired three phasecurrents, which are used for DC/AC inverter control.

IV. SLIDING MODE CONTROLLER

The sliding mode control calculation depends on the outline of a irregular control, which constrains the system towards uncommon manifolds in the system state space. These manifolds are picked with the end goal that the system will have the attractive execution as the system state focalizes to them. The fundamental favorable position of the SMC is one of controllers which ready to give great execution with systems which have high non-linearity. In earlier decades, the SMC has a generally acknowledged in light of the fact that the utilization of direct settled non-straight input control calculations, which work adequately through a specific wide extent scope of system parameter varieties and aggravations. The principle normal for SMC is that the broken non-direct input control switches on at least one various in the state space. The outline of the control system will be seen for state space non-direct system as takes after

$\dot{x}(t) = A(x, t) + B(x, t)u(x, t) + d(x, t)$ (26)

In SMC, the main target is to maintain the system motion on themanifold σ, which is defined as [22]

$s = \dot{e} + Ce$

$e = w_{ref} - v$ (27)

where C is a positive constant and e is the error signal. Where C is a positive constant, e is the error signal and ωref is the reference speed. From the second theorem Lyapunov, the stabilitycondition can be written as following

THD Value Comparison of Induction Motor current for Variations in Wind Speed Step

$\frac{1}{2}.d^2s/dt^2 \leq -K\, s\, |\sigma|$ (28)

where (1/2)σ2 > 0 (positive definite) is a Lyapunov function and K apositive constant [22], which mean

$\sigma \geq 0$ (29)

For constant reference speed then

$\dot{e} = -\dot{v}$ (30)

The switching surface of the speed is designed as following

$s = l[\, e + (kg - m)\int edt] \leq 0$ (31)

where m = f/J, g = (3pLm/2JLr)lr, l is a positive constant and k ischosen so that (kg − m) is positive. The reference current i*qs(output of the proposed SMC) can be written as following

$i^*qs = ke + \boldsymbol{\lambda}_c \text{sign}(\sigma v) - (m/g)w^*m$ (32)

lc is designed as the upper bound of uncertainties, sign(.) is a signfunction defined as

sign(s)=[+1 if σ>0

−1 if σ<0 (33)

The SMC speed controller given by (31) will result in controlchattering. To reduce chattering of the SMC, we replace theswitching control sign(.) in (31) by its smooth approximation (lcsat(σ/ε)) and obtain the speed controller as follow

Table 1.THD Value Comparison of Induction Motor

Control method	Total Harmonic distortion
Proposed Method	25.03%
PID control	109.01%
ANFIS control	15.24%

current for Variations in Wind Speed Step.

$I^{m*}_{qs} = ke + \lambda c\ \text{sat}(\sigma_w/\varepsilon) - (m/g)w^*m$ (34)

whereεis a positive constant representing the boundary layer set forthe switching surface. Then

sat(s) =+1 if $\sigma > \varepsilon$

1if $\sigma = \varepsilon$

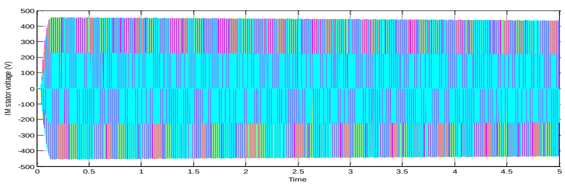
−1 if $\sigma < \varepsilon$ (35)

Table 2. THD Value Comparison of Induction Motor

Control method	Total Harmonic distortion
Proposed Method	25.03%
PID control	112.00%
ANFIS control	15.33%

current for Variations in induction motor speed.

V. SIMULATION RESULTS



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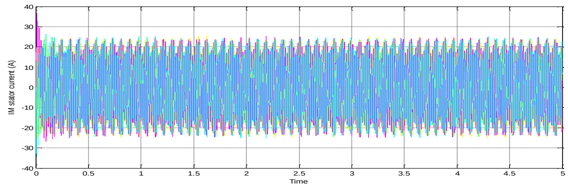

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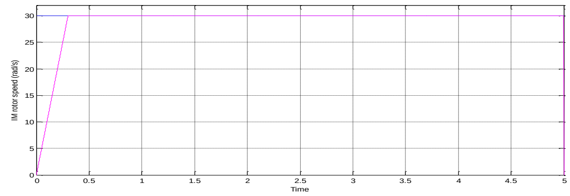


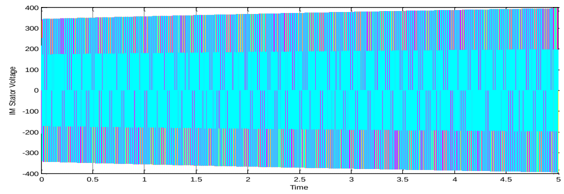
c)

Figure 5. Dynamic response of isolated wind/storage generation unit powered dynamic load with the proposed control for wind speed step

a)IM stator voltage (V)

b)IM stator current (A)

c)IM rotor speed (rad/s)



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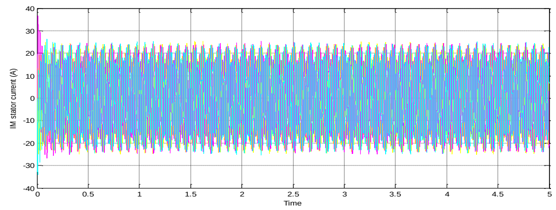

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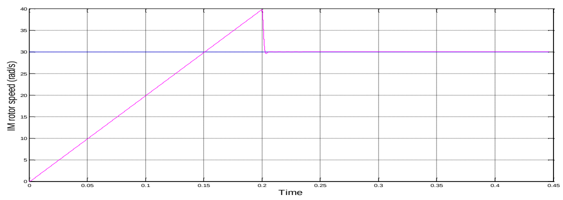


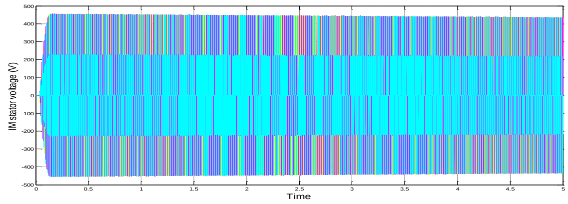
(c)

Figure 6. Dynamic response of isolated wind/storage generation unit powered dynamic load with the PID control for wind speed step

hIM stator voltage (V)

iIM stator current (A)

jIM rotor speed (rad/s)



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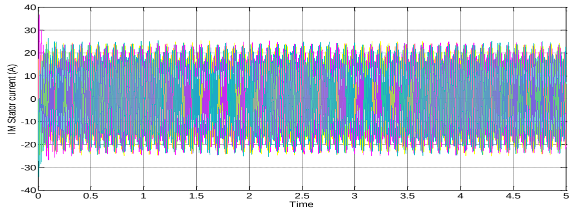

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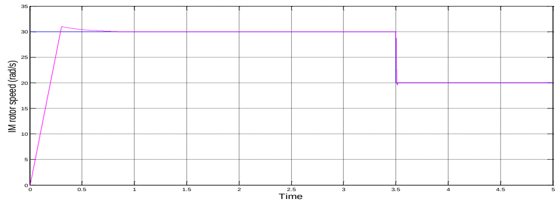


c)

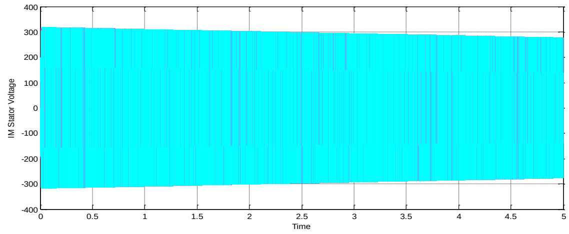
Figure 7. Dynamic response of isolated wind/storage generation unit powered dynamic load with the proposed control for step variations in IM speed and valve

opening (%)

a)IM stator voltage (V)

b)IM stator current (A)

c)IM rotor speed (rad/s)



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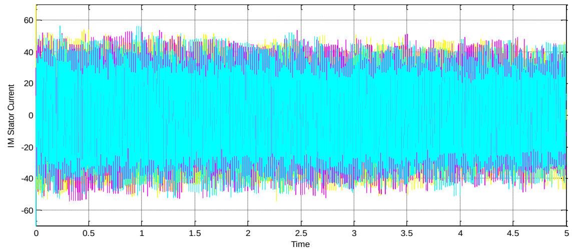

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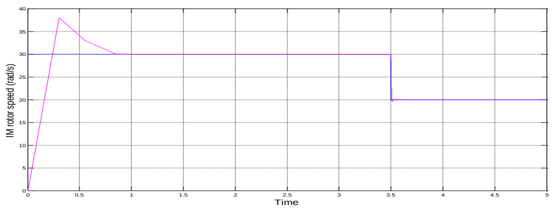


c)

Figure 8. Dynamic response of isolated wind/storage generation unit powered dynamic load with the PID control for step variations in IM speed and valveopening (%)

a)IM stator voltage (V)

b)IM stator current (A)

iIM rotor speed (rad/s)

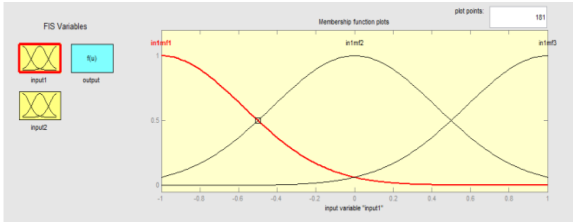
VI. EXTENSION

Artificial Neural Networks

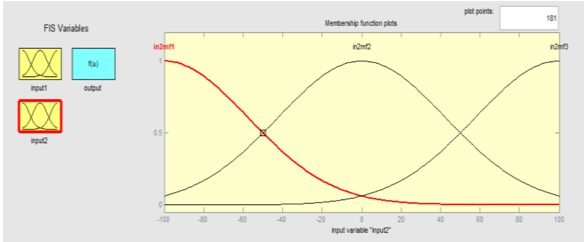
Generally, an artificial neural network (ANN) is a system developed for information processing, where it has a similar way with the characteristics of biological neural systems. ANN is designed to resemble the brain systems such as the construction of architectural structures, learning techniques, and operating techniques. This is the reason that ANN has been widely adopted by scientists because of its accuracy and its ability to develop complex nonlinear models and is used to solve a wide variety of tasks, especially in the field of climate and weather.

Adaptive Neuro-Fuzzy Interference System

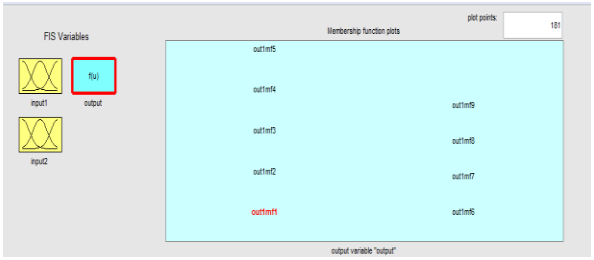
Modify network-based fuzzy inference (ANFIS) is a combination of two soft-computing methods of ANN and fuzzy logic (Jang 1993). Fuzzy logic has the ability to change the qualitative aspects of human knowledge and insights into the process of precise quantitative analysis. However, it does not have a defined method that can be used as a guide in the process of transformation and human thought into rule base fuzzy inference system (FIS), and it also takes quite a long time to adjust the membership functions (MFs) (Jang 1993). Unlike ANN, it has a higher capability in the learning process to adapt to its environment. Therefore, the ANN can be used to automatically adjust the MFs and reduce the rate of errors in the determination of rules in fuzzy logic. This section will describe in details of the architecture of ANFIS, FISs, and network flexibility, and hybrid learning algorithm.



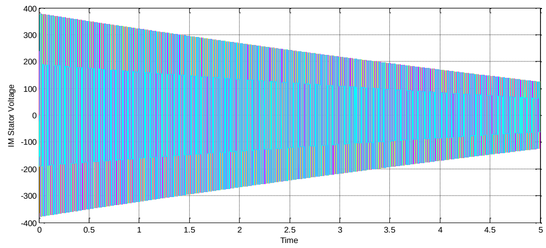
Input 1



Input 2



output



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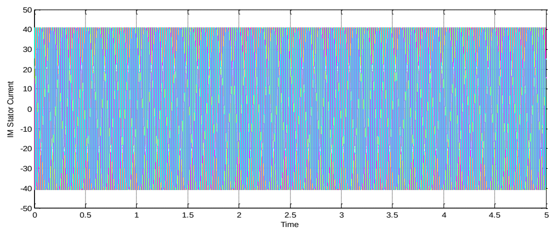

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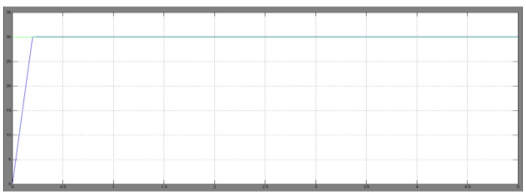
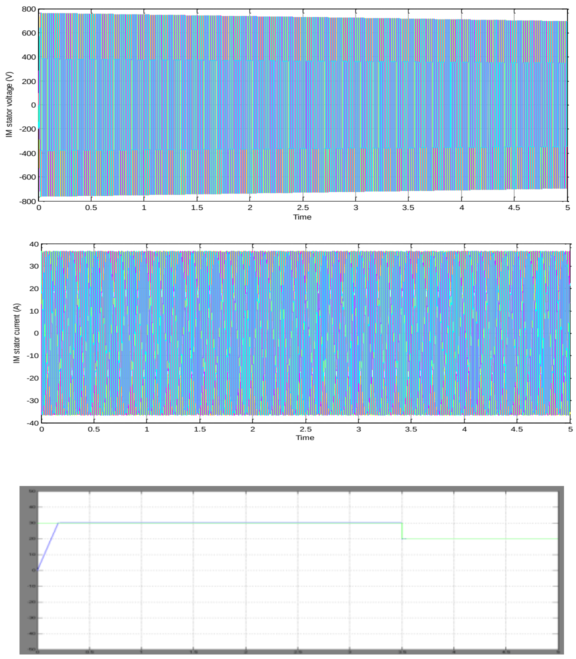


c)

Figure 9.Dynamic response of isolated wind/storage generation unit powered dynamic load based on theANFIS control for wind speed step

aIM stator voltage (V)
bIM stator current (A)
cIM rotor speed (rad/s)



IM Rotor Speed

Figure 10. Dynamic response of isolated wind/storage generation unit powered dynamic load based on theANFIS control for step variations in IM rotor

speed and valve opening (%)
aIM stator voltage (V)
bIM stator current (A)
cIM rotor speed (rad/s)

VII. CONCLUSIONS

This paper researches the application and execution changes of a self-governing wind age unit controlled IM-VDPC pump system in light of sliding mode control. This incorporates a related energyloading unit, with the part to balance out the output voltage in remain single applications. The principle commitment of this paper is the outline of control systems which accomplishes DC-interface voltage, battery condition of accuse observing of ideal conditions for battery charging, IM rotor speed direction in view of vector control and VDPC current rate and pressure direction. Reenactment comes about have been completed to assess the adequacy of the proposed system. The proposed wind-battery age system controlled IM-direct unit with the proposed controller has been tried through advance change in wind speed, pump valve opening% and IM rotor speed. The outcomes demonstrate thatthe proposed controllers are effective in execution upgrade and providing the IM-VDPC draw system from variable speed wind/loading power age system and keeping up the system factors in their coveted conditions against wind speed, pump valve opening% and IM rotor speed trip. The reenactment comes about likewise demonstrate that if there should arise an occurrence of the proposed vector control in light of sliding SMC and neural system control, the system has better execution if there should be an occurrence of less settling time, less most extreme overshoot and less swell contrasted and the traditional PID controller. This investigation likewise demonstrates that utilizing the capacity battery in parallel with the wind age unit can ensure consistent power providing.

VIII. REFERENCES

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