A NOVEL DYNAMIC ERROR DRIVEN TRACKING CONTRLLER FOR PV POWERED PMDC MOTOR DRIVES

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ABSTRACT

This paper presents a robust different control strategy for a photovoltaic PV-powered permanent magnet DC (PMDC) motor drive system that ensures speed reference tracking and energy utilization efficiency, drive reliability and operation flexibility. A low cost Type- B (DC-DC) chopper is employed to control the power transfer from the PV array to the PMDC motor. A novel dynamic tri loop error driven controller is designed and utilized in the proposed PV powered-PMDC motor drive system. The dynamic performance of the tri-loop controller is digitally simulated and validated using the Matlab/Simulink/Sim-Power Software Environment. All unified study system sub-models comprising the PV array, DC-DC converter, PMDC motor, interface filters and dynamic controller are fully discussed.

I. INTRODUCTION

Photovoltaic PVA-solar powered electrical systems comprise different components and subsystems to be controlled separately. Since the generated solar power is dependant on uncontrollable environmental conditions, it requires extra caution to design controllers that handle unpredictable events and maintain efficient load matching power. In this study, a PV solar array model is developed for Matlab/Simulink GUI environment and controlled using the proposed PID controller. The dynamic PID controller's performances is enhanced using tri loop activation to improve PV array-load bus maximum power matching condition, maintaining the DC load bus voltage at constant value as well as tracking a given reference trajectory such as moving a robot arm, a door, or a radar at a certain position. The novel tri-loop error driven controllers has flexible design criteria's so that they can easily be modified and extended for controlling different systems [1].

One of the key challenging issues of PV array schemes is the power matching problem between the PV array and the load. Since the power generated by PV array is unpredictable due to changing solar irradiation level and ambient temperature, it is an important task to maintain a constant load voltage and power. Besides, the load being powered from the PV array may have excursions and switch on/off cases that affect the power matching. Since the output voltage of a PV array also depends on the current drawn from the array, load switching and excursions affect the array output voltage. Therefore the control problems in a PV array system are multi-dimensional and require multi-loop dynamic error driven approaches to extend the single input single output (SISO) controllers for handling systems that require multi input multi output (MIMO) controllers. The use of dynamic error loop supported PID controller turns the MIMO control problem into a SISO control problem eliminating and replacing the complexity by a simpler process [2].

The PMDC motor is used to drive a constant torque load, a pump type load or a position system, which may be radar, a door, or a robot arm positioning system. Each one of these load types requires different control strategies and different controller parameters. Therefore the controllers used in such a system must handle all the cases with an adaptive property in nature. The addition of dynamic error driven loops the controller structures increases the ability of the controllers to handle the changes occurring in the overall system [3]. The tri-loop PID control has been used in three different parts of the solar PV powered PMDC motor drive scheme studied here. One of these parts is the speed reference tracking, DC load bus voltage control and the third part is the optimal maximum power utilization by matching the PV source array to the dynamic load Volt-Ampere Characteristic.

The tri-loop dynamic error driven PID controller has been used in three different parts of the solar PV powered PMDC motor drive scheme studied here. These parts are the speed reference tracking, DC load bus voltage control and the optimal maximum power utilization by matching the PV source array power to the dynamic load volt-ampere characteristics. The third part here deals with PV array maximum power point (MPP) tracking which is a hot issue in PV array utilization, so that many research have been going on [4-14] related to this topic. The MPP tracking controller, which is one of the key parts of this work has been discussed and presented in detail by Altas and Sharaf [13,14] and is not going to be repeated here. Therefore, the application of tri-loop dynamic error driven PID controller is discussed for controlling the DC load bus voltage and the reference speed tracking of the PMDC motor load.

II. GENERAL SYSTEM DESCRIPTION

Fig. 1 shows the proposed stand-alone photovoltaic scheme. This system comprises resistive load and a motorized load. All the motorized and resistive loads are variables as well as the ambient temperature and solar irradiation level.

The proposed cottage PV energy system has the following parts:

I. PV array string of serries/parallel modules. PV array is connected with charger regulator which is a Backup Battery which is used during the night and as power storage. The PV array modelling has been discussed in [15] and will not be repeated here.

II. Power conditioner circuits.
   a) Blocking Diode: To block the reverse current flow.
   b) DC side filter (R_f, L_f): The DC side filter allows for a valid quasi static model of the PV array and ensures sufficient time scale decoupling of the three supplementary control loop.
   c) Type B MOSFET or IGBT DC/DC converter (chopper) using Pulse Width Modulated (PWM) switching circuit.

III. Input side Capacitor (C_I): It's a large value capacitor works as storage media. Loads: Here the loads are hybrid type consists of both resistive and dc motor. The motorized load is permanent magnet DC motor.

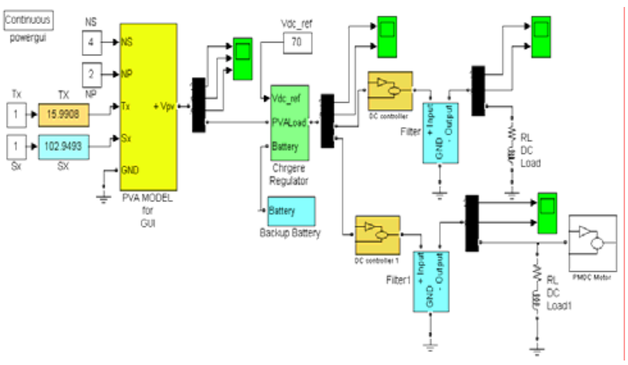

Fig 1. Standalone PV Photovoltaic powered PMDC Motor Drive Utilization Scheme.

The proposed stand alone PV powered load system consists of DC part, which is a PMDC motor and resistors. They are used as DC motorized and resistive loads as shown in Fig. 2. Generated DC voltage of the PV array is controlled to give the needed value of the DC voltage. A single loop classical PI Controller is used to control the DC voltage which is used to feed the PMDC motor. DC controller is shown in Fig. 3.

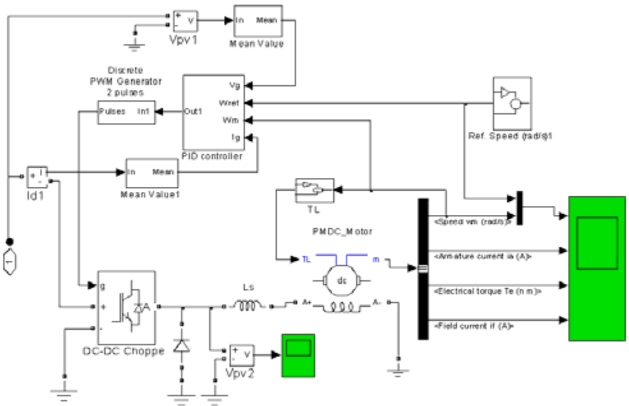

Fig. 2. Simulink Model of the DC-Side Utilization Scheme

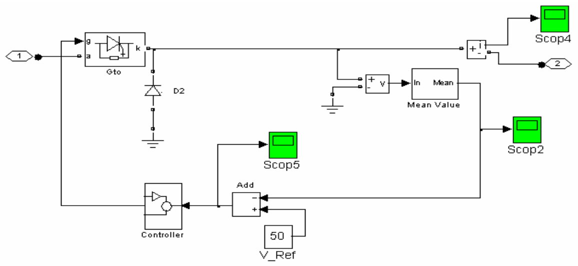

Fig. 3. DC motor drive speed control Scheme

III. DYNAMIC ERROR DRIVEN CONTROLLER

The proposed Tri Loop Error Driven PID controller, developed by the first author and given in Fig. 4, is a novel advanced regulator that operates as an adaptive type multi purpose controller capable of handling parameter changes and load and /or source excursions. The total error signal used by the classical PID controller is the sum of three different dynamic error signals called dominant speed tracking error, voltage ripple blocking error, and power ripple blocking error.

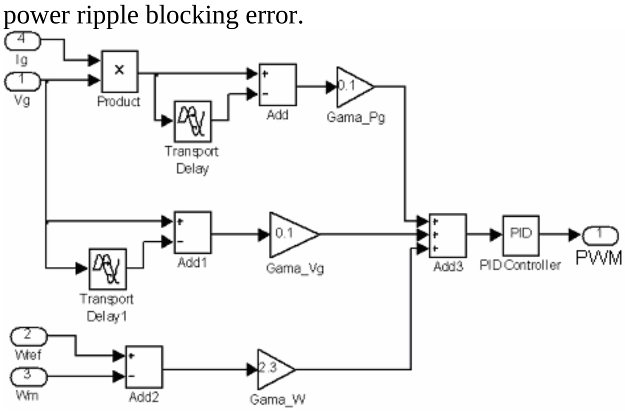

Fig. 4. Tri loop Dynamic Error Driven PID Controller

The dominant speed error is just the difference between the reference and the operating speed as in classical case, which is shown at the bottom part of Fig. 4. The second dynamic error loop is the voltage ripple loop as shown in the middle part of Fig. 4. Two consecutive values of the applied voltage is compared and the weighted difference is used as a voltage ripple error signal to be compensated. This loop ensure safe and stable voltage operation of the PMDC motor by preventing sudden voltage rising due to switched capacitors used in the filter circuits of the DC-DC chopper. The third loop given at the top of Fig. 4 is the dynamic power change loop. The power change loop is used to limit the changes of the motor power so that the motor is not overloaded by the changes in source voltage and current. Since the PV source power may change depending on the weather conditions, this change must be controlled to have a stable and reliable motor operation. The weighting factors in three loops have been obtained for a smooth and stable operation. These weighting factors are selected by considering motor ratings and operational limits.

In order to include the effects of DC-DC chopper switching, the PMDC motor model used in the simulation should be a switched mode model. Therefore, as the chopped DC voltage is applied to the motor, the energy stored in armature winding and rotating armature mass is included in the model. By using the Tri Loop Error Driven PID controller, it is expected to have a smoother, overshoot free, fast and more sensitive speed controller when compared to those of classical ones [16].

The proposed general Switched Mode PV-PMDC Motor Drive Model with the novel Tri Loop Error Driven PID speed controller are fully validated in this paper for effective speed trajectory tracking of the PMDC motor drive under different photovoltaic excursions, loading conditions and parameter variations; such as being fed by a PV array voltage source whose voltage may suddenly change due to solar irradiation and temperature changes while driving a complex mechanical load with a parameter sensitive and non-linear torque-speed characteristics. The tri loop dynamic error driven PID Controller scheme inherently allows any dynamic excursions or parameter variations to be taken into account so that the controller regulator parameters are dynamically adapted by reducing the error changes in the motor parameters [17].

IV. SWITCH MODE MODELLING OF THE PULSED DC MOTOR

A general circuit diagram of the chopper controlled PMDC motor system under consideration is shown in Fig. 2 where the dc chopper including voltage and current filtering elements is clearly depicted. Some waveforms related to the circuit of Fig. 2 are shown in Fig.6, where the load current i_a has a continuous waveform with four parts that each one is conducted by different MOSFET switches and diodes. During the period T_{ON}, the MOSFET M1 is turned on, and the MOSFET M2 is turned off so that the voltage across the input terminals of the chopper is applied directly to the load terminals marked as A and B in Fig. 5. The conducting period T_{ON} of M1 is determined by controller which is used to generate the required pulses, and hence the chopper duty cycle ratio, C [18].

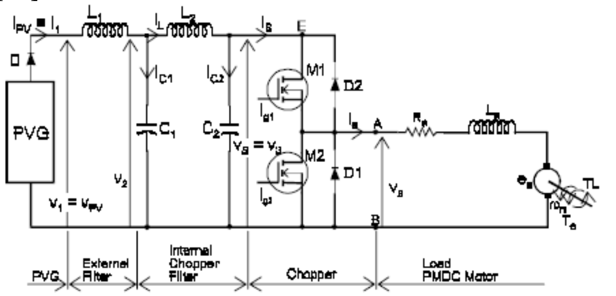

Fig.5. PV Powered DC Chopper - PMDC motor scheme.

Where, T_{MAX} is the maximum chopping period. Depending on the potential levels of points A and B, either M1 or M2 conducts the load current. If M2 is turned on while M1 is off, the voltage across the load terminals, A and B, becomes zero. However, due to the energy storage elements, inductance and the inertia, of the motor, the current i_a does not become zero instantly, and continuous to flow through the diode D1. Diode D2 starts transferring the negative load current i_a to the input side of the chopper when M1 is on and M2 is off. This operating sequence is repeated for each chopping cycle, T_{CH}.

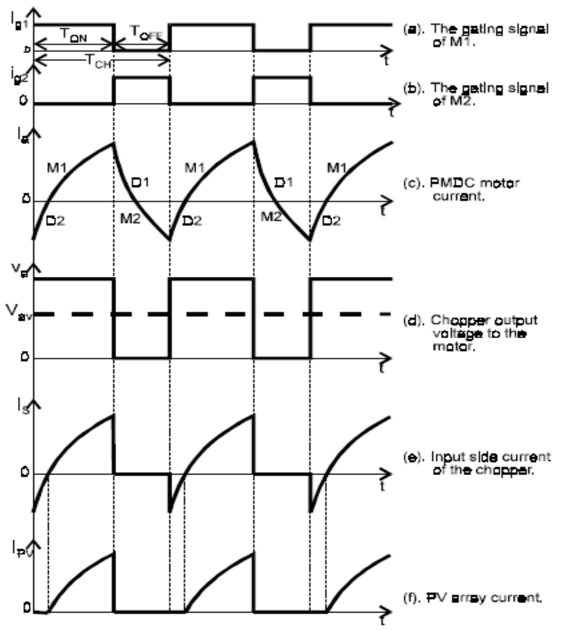

Fig. 6.Basic waveforms of a type B chopper circuit.

The overall system is simulated in two operating stages depending on the operating mode of the chopper.

Operating Stage 1

During the conducting period of the M1 and D2, the chopper circuits, except the filter part, can be omitted to yield a more simplified circuit diagram consisting of the PV array, external filter, internal filter of the chopper circuit, and the PMDC motor. The PV array output voltage $V_{pv}=V_1$ is obtained from the PV array model using the array current $i_{pv}=i_1$, solar irradiation level S_x and ambient temperature T_x as inputs. Therefore, it is assumed that the array voltage $V_{pv}=V_1$is known for the all cases. Under these conditions, the following four simultaneous ordinary differential equations with six unknowns are obtained.

$$\frac{d}{dt}\begin{bmatrix} i_1 \\ i_L \\ v_2 \\ v_3 \\ i_a \\ \omega_m \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1/L_1 & 0 & 0 & 0 \\ 0 & 0 & -1/L_2 & 0 & 0 & 0 \\ 1/C_1 & -1/C_1 & 0 & 0 & 0 & 0 \\ 0 & 1/C_2 & 0 & 0 & -1/C_2 & 0 \\ 0 & 0 & 0 & 1/L_a & -R_a/L_a & -K_V/L_a \\ 0 & 0 & 0 & 0 & K_V/J_m & -B_m/J_m \end{bmatrix} \begin{bmatrix} i_1 \\ i_L \\ v_2 \\ v_3 \\ i_a \\ \omega_m \end{bmatrix} + \begin{bmatrix} V_1/L_1 \\ V_1/L_2 \\ 0 \\ 0 \\ 0 \\ -T_L/J_m \end{bmatrix} \quad (1)$$

Where the load torque is given by

$$T_L = K_0 + K_1\omega_m + K_2\omega_m^2 \quad (2)$$

Where the coefficients K_0, K_1, and K_2 were chosen to represent a pup type load. The numerical values of these coefficients along with all of the other required data for the chopper filter and PMDC motor are given in Appendix.

Operating Stage 2

When M2 or D1 conducts, the points E and A are disconnected while a short circuit occurs between the points A and B. Due to this change, the following two equations are obtained.

$$i_{C2} = i_L \text{ and } 0 = R_a i_a + L_a\frac{di_a}{dt} + e_a \quad (3)$$

Where $e_a = k_v\omega_m$

Thus, Equations (4) and (5) must be modified and replaced by the following equations for the second stage.

$$\frac{dv_3}{dt} = \frac{i_L}{C_2} \text{ and } \frac{di_a}{dt} = \frac{-R_a i_a - K_v\omega_m}{L_a} \quad (4)$$

All of the other equations obtained for stage 1 can be used for the second stage, as well. The overall system is simulated using Matlab/Simulink. Therefore all of the components shown in fig. 5 are modelled for Simulink GUI environment besides the controllers used to generate the gate signals of the chopper for PMDC motor speed control. The simulation diagram of the PMDC motor used in Simulink is shown in Fig. 2 [19, 20].

IV. DIGITAL SIMULATION RESULTS

The full PV conversion scheme was digitally simulated using MATLAB/SIMULIK software. The Solar cell equivalent circuit was created as a block called PV source as shown in figure 1 which simulates the nonlinear V-I characteristics of the solar panel based on the relationship. The speed of the PMDC Motor on DC part is controlled trough an A type DC-DC chopper using the tri loop controller, which is developed by the first author. Three-loop dynamic error driven controller uses voltage and current variations as additional control signals besides the speed feedback to handle any excursion occurs due to load variations or due to solar irradiation and temperature variations on PV side.

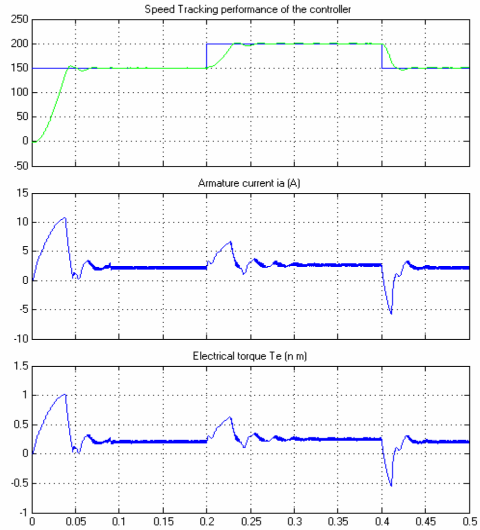

Fig. 7. Speed, current and torque responses of the PMDC motor for step changes in speed reference.

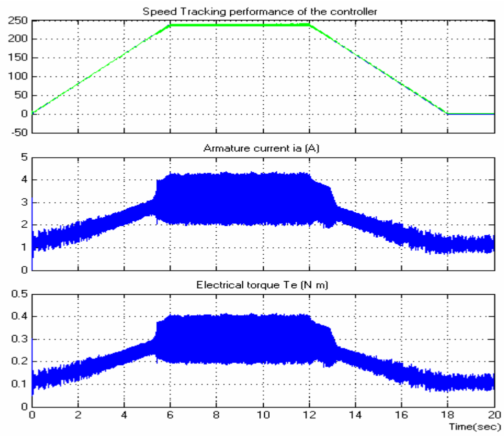

Fig. 8. Speed, current and torque responses of the PMDC motor for ramp type references

The motor speed, current and torque of the PMDC motor are depicted in Fig. 7 and Fig.8. The tracking performance of the tri-loop dynamic error driven controller is shown in Fig.7 and Fig. 8 for step and ramp changes in reference input. The simulation results confirm that the motor speed can be kept at desired levels while ensuring a stable and continuous operation of the PV panel.

V. CONCLUSION

The paper presents a novel dynamic tri loop error driven speed and maximum PV power controller for the standalone PV powered PMDC motor drive. Digital simulation results validated the two essential requirements of Speed reference tracking and near efficient photovoltaic maximum power utilization under solar Irradiation, temperature changes as well as sudden load excursions. The PV array output power has increased by almost 10% using the dynamic power loop for the search of new operating voltage and current that ensures near maximum power condition. The proposed low cost standalone PV powered motor scheme has no backup batteries or online voltage regulator. The time scaled tri-loop dynamic controller varies the pulse width modulation sequence of the DC chopper to provide a near dynamic Volt-Ampere Source-Load matching in addition of tracking the speed trajectory. The novel dynamic tri loop controller developed by the First Author continuously searches for best near maximum PV power utilization level in addition to speed reference tracking. The same dynamic controller is now being tested for other new Photovoltaic powered position control applications including guided vehicle, Electric Car, Ventilation and Pumping. PV standalone schemes are now very attractive for small scale applications Village- Electricity Lighting and Irrigation. PV- Powered Systems utilization in Air-Conditioning can be a can be an as an effective measure for electric utility system capacity release and demand side management.

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APPENDIX

(a) Study PMDC motor parameters:

R_a= resistance of armature winding =1.4 Ohm
L_a= inductance of armature winding = 0.0805 H
K_m= voltage constant = 0.095 V/rad
K_t = torque constant = 0.095 Nm/A.
J_m= moment of inertia = 0.0007432 kg
B_m= viscous constant = 0.000431 Vs/rad.
V_a= Nominal armature voltage =36 V

(b) PID Tri-loop Controller parameters:

K_p =0.5, K_i =0.05, K_d =0.001.

γ_P =0.1, γ_V =0.1,

γ_w =2.3. (Dominant speed loop weighting).