Non-Linear Control SCHEME for MPPT in Photovoltaic System using P&O Algorithm AND COMPARE IT WITH DeSIGNED BACK-STEPPING TECHNIQUE.

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Abstract- **The Increasing energy demands, draining ammonite fuels and growing global warming because of emission of carbon has increased the demand for a substitute, effective and environment attractive power method. The energy from photovoltaic is considered extremely useful and environmentally friendly alternative source of energy. The Photovoltaic (PV) structures have acquired a great deal of interest due to their distinct features such as ease of allocation, less maintenance cost, and widely distributed throughout the earth. However, the main concern about the photovoltaic system is its low efficiency because of varying environmental conditions like a change in temperature and irradiance level. In order to boost up the efficiency of PV system, an MPPT algorithm is a desire to carry out maximum available power from the arrangement of Photovoltaic. This paper is concerned with the nonlinear controller for tracking the maximum power from PV. For this purpose, Non-Linear back stepping Controller is suggested. To connect the load with Photovoltaic, Non-Linear Buck-Boost Converter is used. The controller reference voltage is produced by Regression Plane. The stability of the system is proved by using control Lyapunov Stability Analysis. To test the working of the controller, SIMULINK platform is used. The gate signal of the converter is used as the input of the Perturb and Observe block. The results of simulation authorize that the suggested controller renders fast and accurate tracking.**

Keywords: MPPT, Back-stepping, Power converters, Photovoltaic, P&O.

1. Introduction:

Renewable energy provides helpful benefits for our varying conditions of weather and present condition of electricity in our country. Increase in the demand of energy, changes occur in the prices of oil that are used in the most of the power generation plants and involvement of the worldwide warming has promoted us to glide towards sustainable and renewable sources of energy [1]. The shortfall of ammonite fuels provides us the penetration that we cannot totally dependent on them. The production of power through renewable sources of energy different from ammonite fuels provide us useful fitness benefits [2]. Renewable sources of energy provide us useful benefits for the environment [3].

The energy from solar is advised to be a most prominent renewable energy source for power generation [4]. In 2015, PV system has achieved a record of adding 55 GW to the total capacity in the world and increased it to about 227 GW. Photovoltaic panels are very useful for environment and installation cost is less as compared to other technologies but their power conversion efficiency is low [5]. In order to boost up the efficiency of PV (PV output power/ PV maximum power); they must handle at maximum power point to achieve the high efficiency [6].

The brief diagram of the PV system is described in Fig.1, which consist of:

1- The generation of electric energy from solar energy is achieved by PV module.
2- The DC-DC power converter is used to transfer the maximum power according to the requirement of the load.
3- MPPT controller is used to extract the maximum power from the photovoltaic array with the help of power converter.
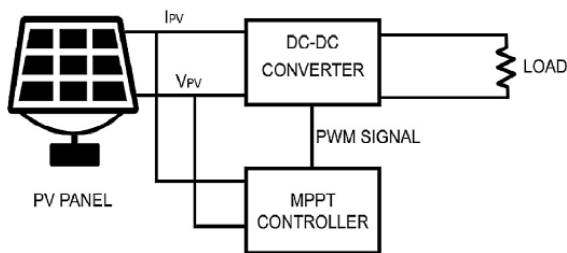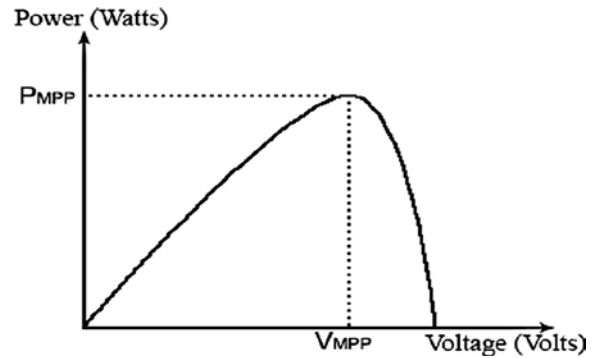4- Nature of Load is Electric.

Figure 1: Block Diagram of MPPT.

Tracking of MPP is the key process of a Photovoltaic system, a lot of research work is finished in this specific area to create new and more efficient MPPT

controllers. Mostly in every MPPT technique, the main idea is to track the V_{mpp} or I_{mpp} points to get maximum power with the help of PV module. The MPP totally rely on the varying environmental conditions i.e. change in temperature and change in irradiance. The PV characteristic curve is shown in Fig.2.

Figure 2: Characteristics Curve of PV.

To understand the working of MPPT, we assume the operation of the charge controller. Whenever a controller is building a discharged battery, it instantly connects the portions of PV to terminals of the battery. The power of PV block, PV voltage and PV current graph describes the established voltage twist and twist in current as describes in Fig.3.
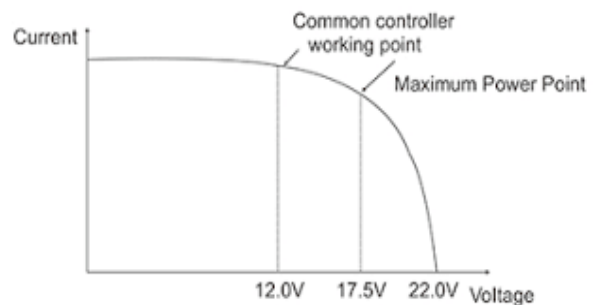
Figure 3: Conventional controller charging curve.

There are different techniques to track the MPP and they are distributed in three primary categories: Conventional Techniques, Artificial Intelligence method, and Population-Based Technique.

P&O [6], [7] and Incremental Conductance (IC) [8] are normally used MPPT methods. P&O is iterative technique. This technique resolves the PV panel operating voltage intermittently and compares output power of photovoltaic with preceding power; the outcoming difference in power (ΔPPV) is processed. Power at different voltage levels (dP = P1 – P2) is calculated as described in Fig.4. If we have positive ΔPPV working voltage perturbation must be in positive direction. If we have negative ΔPPV the operating point retrieved moves far from MPPT,
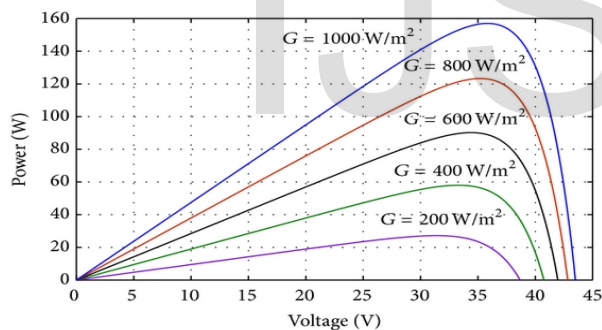
working voltage might be in the reverse path of increment, in this situation perturbation moves back in same direction of MPP. P&O algorithm is described in Table 2.

Figure 4: Power at Different Voltage Levels.

In Incremental Conductance method, change in power with respect to the voltage dP/dV is checked. Comparison of instantaneous conductance (I /V) to the incremental conductance (dP/dV) is done in this method. If on comparison, instantaneous conductance

(I /V) with incremental conductance (dP/dV) lies at zero, its value is close to MPP. If comparison is done between instantaneous conductance (I /V) with, incremental conductance is larger than zero, its value lies on left of MPP. If comparison is done in the instantaneous conductance and incremental conductance is lower than zero, its value lies right of

Technique	Current Perturbation	Difference in Power	Next Perturbation	
		Conversion Efficiency (%)		
	+	Irradiation of 1000qw/sqm	Temperature of 25'C	+
INC		80.7	84	
P&O	−	87.8 +	89.11	−
MP&O	−	94.8 −	+ 94.214	
	+	−	−	

MPP. The main problem with these methods is that, it has large number of perturbation steps, a chance is that we cannot achieve MPP and there is oscillations around MPP that results in loss of power.

Table 1: Conversion Efficiency of P&O.

Table 2: P&O Perturbation.

Techniques that are based on Artificial Intelligence for tracking MPPT includes Neural Network and Fuzzy Logic. The working principle of NN is that it processes with an arrangement that accepts input, manipulates the data and finally gives an output. The advantage of the suggested controller is that it has low manipulation requirement and its tracking speed is very fast regardless of which PV module is used. In [9], the author suggests the ANFIS recognized MPPT method. To develop ANFIS the temperature levels and irradiance levels are taken as inputs. The ANFIS works rightly under changing temperature levels and irradiance levels. These MPPT methods require a large database, large computation time and size of memory is also large. FLC does not need a

mathematical model that is why it is very simple for FLC to handle the non-linearity [10]. FLC based MPPT has good performance in changing irradiance level but it needs a good rule-based table. The author has suggested an adaptive FLC, which are divided into two different rules. In first rule, the duty cycle of the power converter is adjusted and in second rule the gain of the controller is adjusted.

Ant Colony Optimization, Genetic Algorithm, and Particle Swarm Optimization have commonly used MPPT techniques. PSO is an iterative based algorithm. In this, the position of the particles is updated to find its satisfactory position. To find the exact result, particle tries to find the best location by comparing the location of its neighbor particle. The suggested algorithm has slow oscillations around the MPP and finds the MPP under varying temperature and irradiance levels. In [11], ACO based MPPT technique is proposed which shows fast convergence in varying environmental conditions. The main idea of this method is to find the shortest possible path to track the MPP. GA based MPPT technique is proposed in [12]. The proposed algorithm has been integrated with P&O, which results in fewer iterations and small population size.

In this paper, comparison of the non-linear backstepping controller and the P&O algorithm is shown. The suggested controller uses regression plane to generate a reference voltage and non-inverted buck-boost controller to track MPP. The non-inverted buck-boost converter is used due to its high capability of MPPT. The non-linear controller is selected due to the non-linear action of the non-inverted buck-boost converter for stability.

2- Modeling of Converter:

The DC-DC converter is use to boost up or boost down a DC voltage [13]. In the proposed technique, a
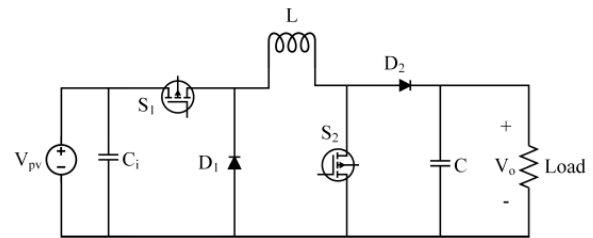
non-inverted buck-boost converter is used. The non-inverted buck-boost converter is used to switch output voltage V_{pv} of PV array to our required V_{MPP} by compensating duty cycle with the support of proposed controller that is backstepping.

Figure 5: Converter Basic Model.

1. Input voltage from PV (Vpv).

2. Insulated-gate bipolar transistor (IGBT) switches (S1 & S2).

3. Inductor (L).

4. Diodes (D1 & D2).

5. Capacitor (Ci & C).

6. Load (L).

It is assumed that the converter is operating in continuous conduction mode. There are two operating modes of the converter i.e. mode 1, in which the switches are on and mode 2, in which switches are off. In mode 1, both IGBT switches (S1 & S2) are ON, a diode (D1) is reverse biased and the load is disconnected due to the closed path by a switch (S2). Inductor (L) is charged from PV through a switch (S1) in this mode. By using Kirchhoff's voltage and current law, we can write

$$\begin{cases} i_{ci} = i_{pv} - i_L \\ \dfrac{dV_{pv}}{dt} = \dfrac{i_{pv}}{C_i} - \dfrac{i_L}{C_i} \end{cases} \qquad (2.1)$$

$$\begin{cases} v_L = v_{pv} \\ \dfrac{di_L}{dt} = \dfrac{v_{pv}}{L} \end{cases} \quad (2.2)$$

$$\begin{cases} i_c = \dfrac{-v_o}{R} \\ \dfrac{dv_o}{dt} = \dfrac{-v_o}{RC} \end{cases}$$

$$(2.3)$$

ici is the input capacitor current, ipv is the PV current and iL is the inductor current, vL is the inductor voltage, vpv is the PV voltage and vo is the output voltage across the load. In mode 2, both switches (S1 & S2) are off and the load is connected to the inductor (L) through the diode (D2). Using Kirchhoff's law, we can write:

$$\begin{cases} i_{ci} = i_{pv} \\ \dfrac{dv_{pv}}{dt} = \dfrac{i_{pv}}{C_i} \end{cases} \quad (2.4)$$

$$\begin{cases} v_L = -v_o \\ \dfrac{di_L}{dt} = \dfrac{-v_o}{L} \end{cases} \quad (2.5)$$

$$\begin{cases} i_c = i_L - \dfrac{v_o}{R} \\ \dfrac{dv_c}{dt} = \dfrac{i_L}{C} - \dfrac{v_o}{RC} \end{cases} \quad (2.6)$$

From inductor volt-second balance and capacitor charge balance, we can write:

$$\begin{cases} \dfrac{dv_{pv}}{dt} = \dfrac{i_{pv}}{C_i} - u\dfrac{i_L}{C_i} \\ \dfrac{di_L}{dt} = u\dfrac{v_{pv}}{L} + u\dfrac{v_o}{L} - \dfrac{v_o}{L} \\ \dfrac{dv_c}{dt} = \dfrac{i_L}{C} - \dfrac{v_o}{RC} - u\dfrac{i_L}{C} \end{cases} \quad (2.7)$$

$$v_o = \dfrac{u}{1-u} v_{in} \quad (2.8)$$

By assuming ideal power transfer i.e. Pi = Po, we can write:

$$R_{pv} = \dfrac{(1-D)^2}{D^2} R_o \quad (2.9)$$

For control design, we will average the model over one switching period and D is the duty cycle. If x_1 is the average value of V_{pv}, x_2 is the average value of i_L, x_3 is the average value of v_c and μ is the average value of u, i.e.

$$\begin{cases} x_1 = < v_{pv} > \\ x_2 = < i_L > \\ x_3 = < v_c > \\ \mu = < u > \end{cases} \quad (2.10)$$

Then the equations of the final model are

$$\dot{x}_1 = \dfrac{I_{pv}}{C_i} - \mu \dfrac{x_2}{C_i} \quad (2.11)$$
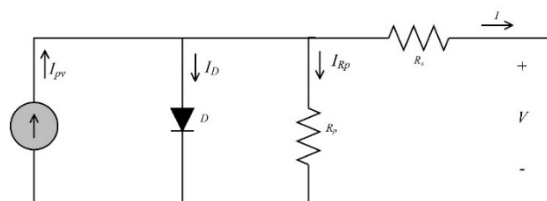
$$\dot{x}_2 = -\dfrac{x_3}{L} + \mu \left(\dfrac{x_1+x_3}{L}\right) \quad (2.12)$$

$$\dot{x}_3 = \dfrac{x_2}{C} - \dfrac{x_3}{RC} - \mu \dfrac{x_2}{C} \quad (2.13)$$

3- Modeling of Photovoltaic Module:

In real operation of solar cell, few losses exist. Losses are shown in a model as series resistance (R_s) and Parallel resistance (R_{sh}) to carry out actual behavior and overcome these losses [14]. The complete model is described in below figure:

Figure 6: PV module basic model.

This model consists of following parameters:

1- D is diode.

2- Series resistance, Rs.
3- Parasitic Resistance, Rsh.
4- Current source Ipv, relying on irradiance level and temperature level.

Using KCL in fig 6, we get:

$$I = I_{PV} - I_d - I_{Rp} \qquad (3.1)$$

$$I_{pv} = \left(\frac{G}{G_{STD}}\right)(I_{pv,STD} + K(T - T_{STD})) \qquad (3.2)$$

G represents current level of irradiance, GSTD is the standard condition for irradiance, Solar cell generates the current Ipv,STD at TSTD and GSTD. K represents Boltzmann Constant. T represents the temperature of p-n junction and the temperature for the standard P-N junction is represented by TSTD [16].

$$I_{d=}I_o\left(exp\frac{q(V+R_sI)}{YkT} - 1\right) \qquad (3.3)$$

Io represents Diode reverse saturation current and can be represented by following equation [17].

$$I_o = \frac{I_{pv,STD} + K_i(T - T_{STD})}{\exp\left(\frac{qV_{oc} + K_v(T - T_{STD})}{YV_t} - 1\right)} \qquad (3.4)$$

Where electron charge is represented by q, PV voltage for the open circuit is Voc, the coefficient for the open circuit is Kv and coefficient for the open circuit is Ki. Thermal voltage for PV module is Vt. Ideality factor for the diode is r.

$$I_{Rp} = \frac{V + R_sI}{R_p} \qquad (3.5)$$

By putting values of PV current I_{pv}, diode current I_d and current through shunt resistance I_{Rp} in equation 1, we get:

$$I = \left(\frac{G}{G_{STD}}\right)\left(I_{pv,STD} + K_i(T - T_{STD})\right)I_0\left(exp\frac{q(V+R_sI)}{YkT} - 1\right) - \frac{V+R_sI}{R_p} \qquad (3.6)$$

By rearranging all above equations, we get the final equation of PV module [18].

$$I = N_p\left(I_{pv} - I_o\left[\exp\left(\frac{V+R_sI}{\frac{N_skT}{q}Y}\right) - 1\right]\right) - \frac{V+R_sI}{R_p} \qquad (3.7)$$

N_s is a series arrangement of cells, N_p is a parallel arrangement of the cell and V is output voltage. R_p represents Parasitic resistance because of leakage current of the p-n junction. R_s is series resistance because of metal contacts connecting PV module.

4- Stability and Design Analysis of Controller:

The main control task is to track Photovoltaic module output voltage V_{pv} to the reference voltage V_{ref} developed from regression plane under changing environmental conditions.

4.1- Reference Voltage Generator V$_{ref}$.

The real-time simulation of regression plane is shown in figure 7. It provides a reference voltage for the backstepping controller to reach MPP under changing irradiance and temperature level.

The VMPP array for changing temperature (00 C - 600 C) and changing irradiance levels from (200 W/m2 - 1000 W/m2) is derived by using photovoltaic
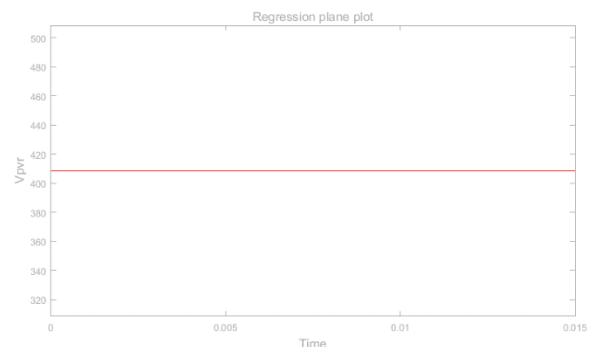
characteristic curve. Using linear interpolation, regression plane is derived which provide us reference voltage i.e. Vpvr for the controller.

Figure 7: Regression plane plot.

The backstepping controller then tracks the V_{pv} to V_{pvr} to achieve the MPP. The derived regression plane equations become

$$V_{pvr} = 579.81 - 1.9899 * \text{Temperature} - 0.12146 * \text{Irradiance}.$$

4.2- Derivation of Back-steeping Control

In order to extract maximum power from PV module, a non-linear back-stepping controller is designed to track the PV module output voltage V_{pv} to V_{MPP} by adjusting the duty cycle of the converter. The first step is to define error signal.

$$e_1 = V_{pv} - V_{pvr} \tag{4.1}$$

V_{pvr} is reference voltage and it is generated by regression plane and V_{pv} is the PV module output voltage. By converging error signal e_1 to zero, we can get our desired result. Taking the derivative of above equation.

$$\dot{e}_1 = \dot{V}_{pv} - \dot{V}_{pvr} \tag{4.2}$$

Using equation 2.11, we get

$$\dot{e}_1 = \frac{I_{pv}}{C_i} - u\frac{x_2}{C_i} - \dot{V}_{pvr} \tag{4.3}$$

Here x_2 is control input in above equation and define V_1 as Lyapunov stability as candidate function. Then it checks error signal convergence and maintains it to the equilibrium point.

$$V_1 = \frac{1}{2}e_1^2 \tag{4.4}$$

Some steps are needed to perform and are defined below:

1- At equation i we must define error signal.
2- After step one, we must rewrite error signal and is denoted by z_i.
3- Control input is represented as x_{i+1}.
4- Find CLF for the system.
5- The expression of stabilizing function is derived by using CLF.

For asymptotic stability, there must positive Lyapunov function defined and is radially unbounded. Its derivative is taken as negative. Taking time derivate of the equation.

$$\dot{V}_1 = e_1 \left(\frac{I_{pv}}{C_i} - u\frac{x_2}{C_i} - \dot{V}_{pvr} \right) \tag{4.5}$$

Derivation of voltage V_1 to become negative, suppose below equation that gives us our desired equation by doing some needful calculations.

$$\frac{I_{pv}}{C_i} - u\frac{x_2}{C_i} - \dot{V}_{pvr} = -k_1 e_1 \tag{4.6}$$

After simple calculations the final equation of x_2 is:

$$x_2 = \left(k_1 e_1 + \frac{i_{pv}}{C_i} - \dot{V}_{pvr} \right) \frac{C_i}{u} \tag{4.7}$$

By replacing the value of x_2 in above equation. We find derivative of voltage V_1. So

$$\dot{V}_1 = -ke_1^2 \tag{4.8}$$

If the derivative of voltage V_1 is negative definite then K_1 must be positive definite and hence satisfied the equation of x_2. β is stabilization function. It behaves as the reference current.

$$\beta = \left(C_i k_1 e_1 + I_{pv} - \dot{V}_{pvr} C_i \right) \frac{1}{u} \tag{4.9}$$

Here we find the value of x_2 to extract the value of stabilization factor β. For this purpose, error signal is defined that is e_2.

$$e_2 = x_2 - \beta \tag{4.10}$$

Rewriting above equation, we get

$$x_2 = e_2 + \beta \tag{4.11}$$

After taking derivative of e_2, the final equation becomes.

$$\dot{e_2} = \dot{x_2} - \dot{\beta} \tag{4.12}$$

By using of the equation of derivative of e_1 and x_2. We find the value of derivative of stabilization factor β.

$$\dot{\beta} = \frac{\mu}{\mu^2}\left(C_i k_i \left(\frac{I_{pv}}{C_i} - \frac{\mu}{c_i}(e_2 + \beta) - \dot{V_{pvr}}\right) + \dot{\iota_{pvr}}\right) - \frac{\mu}{\mu^2}\ddot{V_{pvr}}C_i - \frac{\dot{\mu}}{\mu^2}\left(C_i k_1 e_1 + i_{pv} - \dot{V_{pvr}}C_i\right) \tag{4.13}$$

By rewriting above equation, we find the simplified equation of derivative of β.

$$\dot{\beta} = \frac{1}{\mu}\left(-C_i k_1^2 e_1 + \dot{I_{pv}} - \ddot{V_{pvr}}C_i\right) - k_1 e_2 - \frac{\dot{\mu}\beta}{\mu} \tag{4.14}$$

Replacing values of derivative of x_2 and β in the equation of derivative of e_2. We get:

$$\dot{e_2} = -\left(\frac{1}{\mu}\left(-C_i k_1^2 e_1 + \dot{I_{pv}} - \ddot{V_{pvr}}C_i\right) - k_1 e_2 - \frac{\dot{\mu}\beta}{\mu}\right) - \frac{x_3}{L} + \mu\left(\frac{x_1 + x_3}{L}\right) \tag{4.15}$$

To assure the stability of the system and the convergence of the errors e_1 and e_2 to zero, a composite Lyapunov function V_c is defined whose time derivative must be negative definite for all x values.

$$V_c = V_1 + \frac{1}{2}e_2^2 \tag{4.16}$$

Taking the derivative of a Lyapunov function, we get.

$$\dot{V_c} = -k_1 e_1^2 - \mu\frac{e_2 e_1}{c_i} + e_2 \dot{e_2} \tag{4.17}$$

Rearranging above equation, we get.

$$\dot{V_c} = -k_1 e_1^2 + e_2\left(\dot{e_2} - \mu\frac{e_1}{c_i}\right) \tag{4.18}$$

Now derivative of e_2 becomes.

$$\dot{e_2} - \mu\frac{e_1}{c_i} = -k_2 e_2 \tag{4.19}$$

By replacing the value of k_2 and derivative of e_2 in above equation, we get:

$$-k_2 e_2 = \mu\left(\frac{x_1 + x_3}{L}\right) - \frac{1}{\mu}\left(-C_i k_1^2 e_1 + \dot{I_{pv}} - \ddot{V_{pvr}}C_i\right) + k_1 e_2 + \frac{\dot{\mu}\beta}{\mu} - \mu\frac{e_1}{C_i} - \frac{x_3}{L} \tag{4.20}$$

Putting values in the equation of derivative of a Lyapunov function, we get:

$$\dot{V_c} = -k_1 e_1^2 + e_2\left[\mu\left(\frac{x_1 + x_3}{L}\right) - \frac{1}{\mu}\left(-C_i k_1^2 e_1 + \dot{I_{pv}} - \ddot{V_{pvr}}C_i\right) + k_1 e_2 + \frac{\dot{\mu}\beta}{\mu} - \mu\frac{e_1}{C_i} - \frac{x_3}{L}\right] \tag{4.21}$$

$$\dot{V_c} = -k_1 e_1^2 - k_2 e_2^2 \tag{4.22}$$

By solving two equations, we get:

$$\dot{\mu} = -\frac{\mu}{\beta}\left(k_2 e_2 - \frac{1}{\mu}\left(-C_i k_1^2 e_1 + \dot{I_{pv}} - \ddot{V_{pvr}}C_i\right) + k_1 e_2\right) - \frac{\mu}{\beta}\left(-\frac{x_3}{L} + \mu\left(\frac{x_1 + x_3}{L}\right) - \mu\frac{e_1}{C_i}\right) \tag{4.23}$$

Final equation for controller becomes.

$$\dot{\mu} = \frac{1}{\beta}\left(e_2(-k_1 - k_2)\mu - e_1\left(C_i k_1^2 - \frac{\mu^2}{C_i}\right) + \mu\frac{x_3}{L}\right) + \frac{1}{\beta}\left(\dot{I_{pv}} - \ddot{V_{pvr}}C_i - \mu^2\left(\frac{x_1 + x_3}{L}\right)\right) \tag{4.24}$$

Where $0 < \mu < 1$ and $\beta \neq 0$.

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