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A model reference adaptive control system for the automatic control of cane feeding system in a cane sugar factory

Maheswary mohan[1], Abhir Raj Metkar[2], Priyanka CP[3]

M Tech Student, EEE, Lourdes Matha College, Trivandrum, India [1]

Control Engineer, Control and Instrumentation Group, C DAC, Trivandrum, India [2]

Assistant Professor, EEE, Lourdes Matha College, Trivandrum, India [3]

Abstract: Cane raw sugar factory consist of a series of chemical and mechanical process. Cane feeding section, milling section, evaporator section etc are the main sections of a cane raw sugar factory. For the steady feed of cane into the milling plant it is very important to control the entire cane feeding system automatically. The manual mode of controlling may trip the entire cane feeding and milling system. This paper describes the automatic control of cane feeding section of a cane raw sugar factory through model reference adaptive control approach(MRAC). The plant model including the dynamics of kicker, leveller, fibrizor, Donnelly chute etc makes the system more complex. In order to reduce the complexity of controlling the entire system a logical control scheme is necessary. Steady feed of cane can be achieved by controlling the speed of cane carrier motor and rake elevator motor. Set point of the cane carrier and rake elevator motor control system can be varied by this logical control scheme for the steady feed of cane into the milling section. A model reference adaptive control system can be use to implement the control scheme. MRAC shows better control performance than a conventional controller.

Keywords: MRAC, MIT rule, PI, PID

I.INTRODUCTION

The main purpose of cane sugar factory is to produce crystallised sugar from the cane raw juice. The cane carrier section carries cane into the milling section for juice extraction. Juice is extracted from the milling section and collected in a juice tank. It is about 35 degree Celsius. It is pumped to raw juice heaters. The purpose of raw juice heating is to destroy or stop the development of microbial activity in the raw juice.
After sulphuration and clarification juice goes to evaporator section. The clear juice contains about 83 to 85% water, the remaining portion being represented by the sugar and impurities known as non-sugar components. Most of this water has to be removed for sucrose crystallization and instead of evaporating all the water necessary for sucrose crystal recover in one stage, for the sake of economizing the energy consumption, an ingenious method was evolved to first get rid of nearly 75% of the water in clear juice in the most economical way and send the concentrated juice known as syrup with 35-45% water to pan station.
The evaporator station which performs the function of concentrating the clear juice to syrup of 60-65% solid content has the most important role to play in the energy saving in the entire cane sugar manufacturing process. Sugar crystallisation occurs in vacuum pan section. In the pan boiling process, the syrup is evaporated until it reaches the super saturation stage.

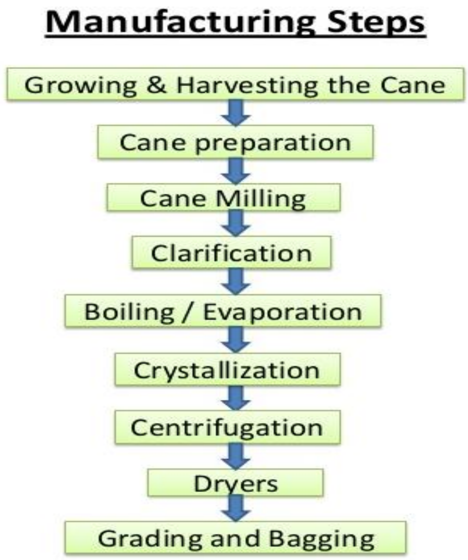

Fig 1: sugar manufacturing process flow chart

For the steady feed of cane into the milling plant it is very important to control the entire cane feeding system automatically. The manual mode of controlling may trip the whole cane feeding and milling system. Cane carrier Motor and rake elevator motor carries cane into the milling plant. The speed of cane carrier and rake elevator motor should be controlled with respect to many parameters like kicker load, leveller load, mat level, Donnelly chute level etc to achieve the desired capacity of production. Manual mode of controlling leads to overload at the first mill. Cane feed and mill automation ensures the designed capacity production without trip and increases the plant output. Steam power is used to drive all four mills. The steam to the turbines is fed from the boilers using the PRDS system. So total five control loops are required for auto cane feeding system.

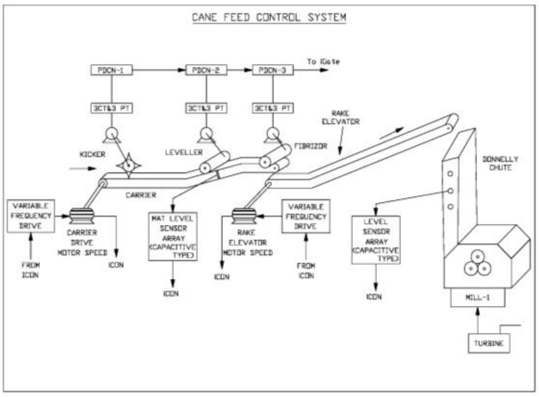

Fig 2: Auto cane feed and mill automation

The cane carrier conveyor control is proposed by using a Dy no drive for electric motor. A three phase squirrel cage induction motor is used as cane carrier motor. The speed of the conveyor is to be controlled to get the constant cane supply. Rake elevator conveyor is another conveyor in continuation with cane carrier [1] .The crushed cane is deposited to the milling section through Donnelly chute from rake elevator section. The cane carrier section consist of some preparatory devices like kicker, leveller, fibrizor etc to cut the cane into small pieces[1]. The rake elevator conveyor speed is proposed to be controlled by a variable frequency drive/ Dy no drive on the electric motor. The speed is controlled with reference to the cane level measured by the level sensor array (capacitive type) on the Donnelly Chute structure. The cane carrier speed and the Mill-1 pressure are also the interlocking parameters for this rake elevator speed control. Cane carrier and rake elevator speed control ensures steady speed of cane into the first mill.

II.AUTOCANE FEEDING CONTROL SCHEME

Kicker load, leveller load, mat level, chute level etc has their own nominal values .If they exceed above their nominal values it will interfere the steady feed of cane into the milling plant[2]. So it is very important to design an auto cane feeding system. The model of the system including the dynamics of kicker, leveller, fibrizor, Donnelly chute etc makes the system complex. So a logical control scheme is necessary to control the entire cane feeding system. If kicker load, Leveller load, mat level, chute level etc changes from their nominal values some new set point values are generated through a function f(x) depend on the requirement. Here 7 new set point values are generated and taking the minimum of all these set point value for the cane carrier and rake elevator motor speed control system to change the speed.

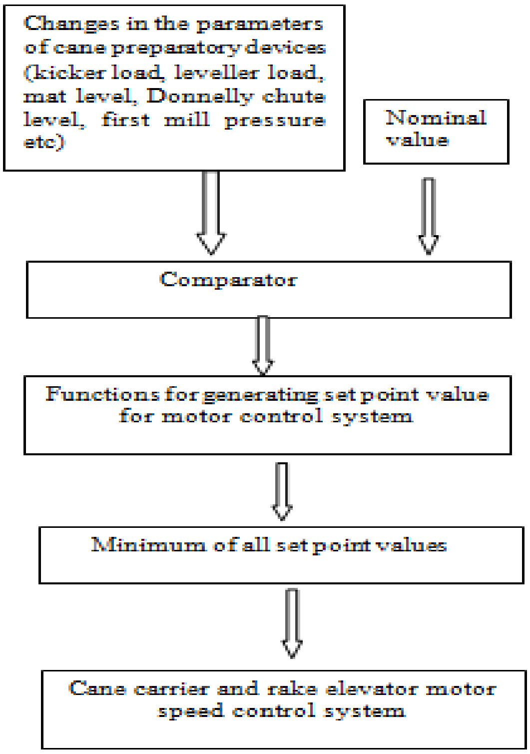

Fig3: Auto cane feeding system loop logic

For implementing the control scheme shown in Fig :3 a motor control scheme is necessary. The logical loop is for changing the set point of that motor control system. The cane carrier motor and rake elevator motor are three phase squirrel cage induction motors.
Induction motor plays vital role in most industrial applications due to its low maintenance and robustness. The theory of reference frame can be used to derive the mathematical model of three phase induction motor. Dynamic modelling approach is one of the best method for understand the behaviour and performance of three phase induction motor. Cane carrier and rake elevator motor nominal speed is 1000rpm. Speed of cane carrier conveyor is 4-10 meter per minute. Rake elevator conveyor seed is 27 meter per minute. Both cane carrier and rake elevator motors are driven by 415 V 50 Hz AC supply. A dynodrive is connected prior to the motors to receive the control signal from the controllers.

III.MOTOR MODEL

The dynamics of three phase induction motor is given by [3]

$$\frac{J d\,\omega(t)}{dt} = T_e(t) - B\,\omega(t) - T_l(t) \quad (1)$$

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Here J is the moment of inertia of the rotational speed, $T_e(t)$ is the electromagnetic torque developed by the motor. B is the damping constant. $T_l(t)$ is the load torque ω is the rotor angular mechanical speed. Electromagnetic torque developed by the motor can be represented by

$$T_e(t) = k_d \psi_{rd}(t) i_{sq}(t) \quad (2)$$

k_d is a positive constant, ψ_{rd} is the direct axis rotor flux linkage

$$\frac{Jd\,\omega(t)}{dt} = k_d \omega_{rd}(t) i_{rq}(t) - B\omega(t) - T_l(t) \quad (3)$$

Taking the Laplace transform of (3) we get the following equations for controlling the speed of a three phase squirrel cage induction motor.

$$JS\,\omega(S) = \frac{k_d \psi_{rd} i_{sq}(s)}{J} - \frac{B}{J}\omega(S) \quad (4)$$

$$S\,\omega(S) = \frac{k_d \psi_{rd}}{J} i_{rq}(s) - \frac{B}{J}\omega(S) \quad (5)$$

Induction motor model introduced here in equation (1) and (2) for certain operating point yields to a first order model given by

$$\omega(s) = \frac{k_p}{s + a_p} \quad (6)$$

$$\frac{k_d \psi_{rd}}{J} = k_p \quad (7)$$

$$\frac{B}{J} = a_p \quad (8)$$

IV.MODEL REFERENCE ADAPTIVE CONTROL

Model reference adaptive control is a control method used by a controller the parameters of the controller are adjusted with respect to changes in the output of the plant. It consists of a reference model, adjustment mechanism and controller. Adjustment mechanism is an inevitable block in model reference adaptive controller approach.

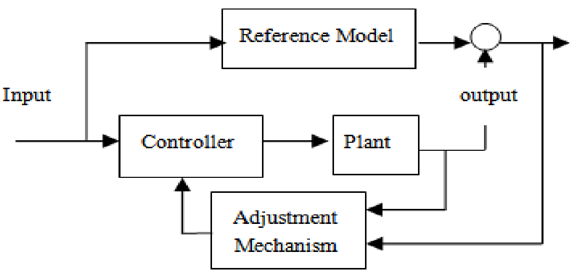

Fig 4: Model reference adaptive control system

Reference model is used to give an idyllic response of the adaptive control system to the reference input. Adjustment mechanism can adjust the parameters of the controller with respect to the changes in the output. So the actual plant can track the reference model.MIT rule, Lyapunov method, Theory of augmented error method can be used to implement adjustment mechanism.

V.MIT RULE

MIT rule was developed by the researchers in Massachusetts institute of technology (MIT) in1960s for adaptation mechanism. We can apply this rule to any practical system [4]. In this rule the cost function is defined by the following equation.

$$F(\theta) = e^2/2 \quad (9)$$

Here 'e' is the error. ie the difference between the output of the actual plant and the model. Here θ is taken as the adjustable parameter. θ is adjust to minimize the cost function. Here the adjustment parameter is kept in the negative gradient of F.

$$\frac{d\theta}{dt} = -\gamma \frac{\partial F}{\partial \theta} \quad (10)$$

$$\frac{d\theta}{dt} = -\gamma e \frac{\partial e}{\partial \theta} \quad (11)$$

Here the partial derivative $\frac{\partial e}{\partial \theta}$ is called sensitivity derivation of the system. We know that error is

$$e(t) = y(t) - y_m(t) \quad (12)$$

The transfer function of the reference model is taken as k_0 G(s).

$$\frac{\partial E(s)}{\partial \theta} = KG(S)U_c(S) = \frac{K}{K_0} y_m(S) \quad (13)$$

$$\frac{d\theta}{dt} = -\gamma e \frac{K_0}{K_m} y_m \quad (14)$$

Equation (14) gives the law for adjusting the parameter θ (MIT rule).

VI. CONTROLLER DESIGN

For model reference adaptive PID controller

$$U = U_c \theta \quad (15)$$

$$U_C = k_p e(t) + k_d \frac{de(t)}{dt} + k_i \int_0^t e(t).dt \quad (16)$$

$$U = [(.004\, e(t) - 6.9 \frac{d(et)}{dt} + 0.081 \int_0^t e(t)dt)\theta] \quad (17)$$

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For model reference adaptive PI controller

$$U = [(.004\, e(t) + 0.081 \int_0^t e(t)dt)\theta] \tag{18}$$

Here U is the model reference adaptive PI controller output and model reference adaptive PID controller output.

The output of the PI or PID controllers are multiplies with the output of the adjustment mechanism to get the require performance. Adjustment mechanism is implemented with MIT rule .Output of the controller is then given as input to the plant to get the desired response.

VII.SIMULATION RESULTS

$$k_d = 21.8, \psi_{rd} = 87.5 \times 10^{-5} \text{ WEBERS } B = 5.65 \times 10^{-3} kgm^2/s,$$
$$J = 5 \times 10^{-4}, kp = 3797.56$$

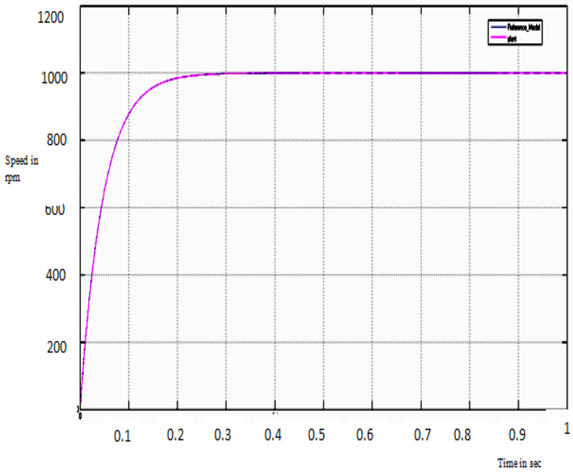

FIG 5: MOTOR SPEED WITH MODEL REFERENCE ADAPTIVE PI CONTROLLER

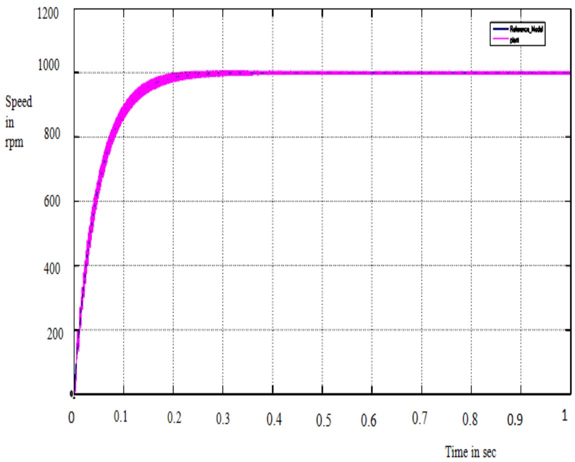

Fig 6: Motor speed with model reference adaptive PID controller

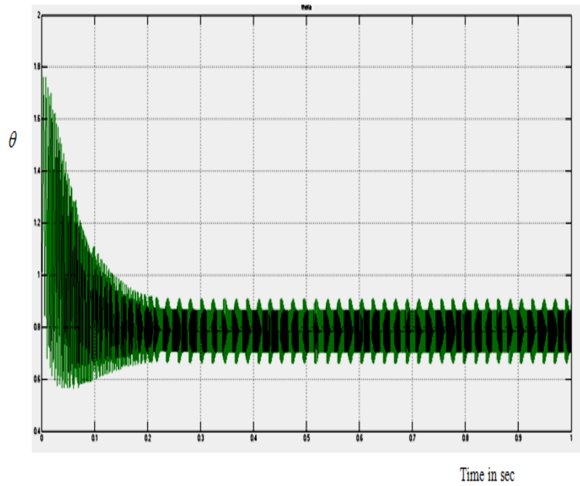

Fig 7: Variation of θ with time for model reference adaptive PI controller

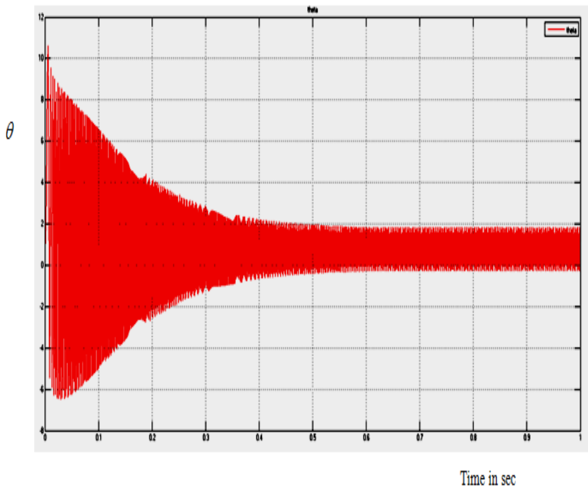

Fig 8: variation of θ with time for model reference adaptive PID controller

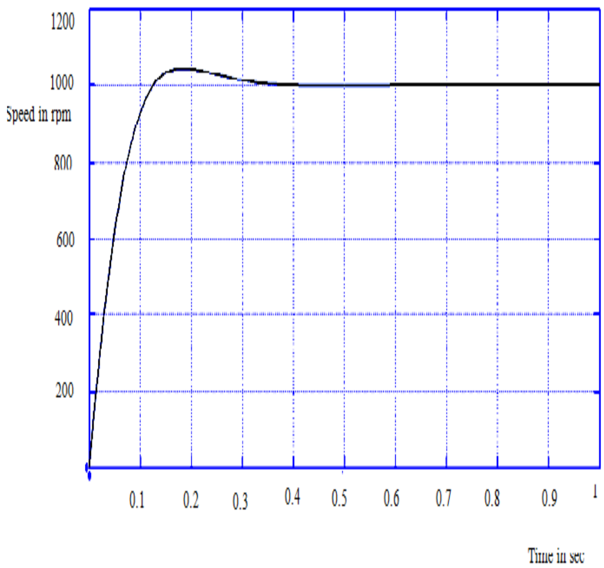

Fig 9: Motor speed with conventional PI controller

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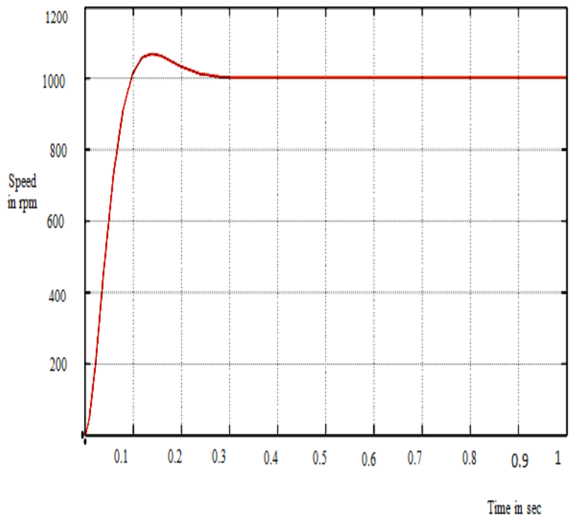

Fig 10: Motor speed with conventional PID controller

TABLE 1
COMPARRISON BETWEEN MRAC AND CONVENTIONAL CONTROLLERS

controller	Settling time(in sec)	Peak over shoot
Model reference adaptive PI	0.25	-
Model reference adaptive PID	0.25	-
Conventional PI	0.32	1050
Conventional PID	0.3	1055

TABLE 11

OUTPUT OF AUTO CANE FEEDING SYSTEM

Kicker load(Nominal value=50A)	Leveller load(Nominal value=100A)	Mat level (Nominal value=0.8m)	First mill chest pressure(Nominal value=18 kg/cm2)	Fibrizor chest pressure(Nominal value=18kg/cm2)	Donnelly chute level (Nominal value=3m)	Juice tank level(Nominal value=1.5m)	Speed of cane carrier motor (in RPM)	Speed of rake elevator motor (in RPM)
50	100	0.8	18	18	3	1.5	1000	1000
55	110	0.88	19.8	19.8	3.3	1.65	850	935
60	120	0.96	21.6	21.6	3.6	1.8	800	880
70	130	0.98	22	22	3.7	1.9	700	770

VIII. CONCLUSION

Steady feed of cane can be achieved by controlling the speed of cane carrier motor and rake elevator motor. The set point to the motors can be changed with the help of a logic loop as per the necessity. A model reference adaptive control approach is used for the speed control of cane carrier and rake elevator motor speed control system. Simulation results show that MRAC shows better performance than conventional controllers. MRAC can reduce the settling time of the process and it can eliminate the peak overshoot.

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