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LOSS MITIGATION IN A RAPID RESPONSE FUZZY LOGIC DRIVEN QBC MULTILEVEL INVERTER FEED INDUCTION MOTOR SYSTEM

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Abstract. A closed loop Fuzzy Logic Controller controlled Quadratic Boost Converter for Multilevel Inverter fed In-duction Motor system is proposed here for loss minimization and THD reduction. An alternate method for connecting the motor and DC supply is a quadratic boost converter with a multilevel inverter. The suggested endeavor considers the QBCMLI system's closed-loop response along with fractional order PID and FLC. The designed system of the converter aims to reduce the output current THD of the IM-drive and circuit modules investigated for FOPID and FLC controlled systems. The simulation results using MATLAB SIMULINK illustrates a developed dynamic performance of speed and torque responses by using FLC controlled QBCMLI system. Switching loss and THD are minimized using FLC.
Keywords: Multilevel inverter, Quadratic boost converter, closed loop response, Fractional Order PID controllers, Induc-tion motor, Fuzzy Logic Controller.

1. Introduction

Converters in view of force gadgets are broadly utilized in an assortment of applications. With the utilization of exorbitant obligation cycles, the fun-damental group of converters, for example, the con-ventional boost and buck-boost, for instance, can potentially provide high-voltage gain. This research looked at, a Quadratic Boost Converter (QBC) to-pology is shown that, when used with a certain pulse width modulation (PWM) approach, significantly reduces yield voltage ripple and energy stored. The focus is on the recent improvements in quadratic converter family. The habitual QBC is of single switch. Few significant properties of designed con-verters: (i) Due to the design's feasibility, quadratic voltage gains, which are easily expanded to cubic as well as other exponential order gains, make automat-ing the installation of commutation cells straight-forward; (ii) a particular commutation method that uses capacitor voltage ripple cancellation to reduce output-voltage ripple with a frequency (double the switching frequency).

The four practicable inductor current discon-tinuous conduction modes analytical description is given in detail for the converter operating under steady-state. Barriers in midst of modes are resolved with comparable transitions [1]. The DC-DC multi-level boost converter (MBC) [2], also described as a pulse width modulated (PWM) converter that com-bines capability of the boost converter and the switched capacitor operations to deliver balanced voltage outputs utilizing with only single driven switch, one inductor, 2N − 1 diode and 2N −

1 capac-itor for an Nx QBC.

The idea of this setup is to get an advanced con-version rate and distinguished effectiveness for a wide source voltage range by utilizing a quadratic boost converter [3-6].

In this article, the current-fed quadratic full-bridge buck converter's dynamic characteristics and operation are briefly discussed. True current-fed converters have an unusually different topology than conventional voltage-fed converters [6], according to their design [7]. The theory of decreased redun-dant power processing provides the foundation for the analysis of a family of switching step-down dc-dc converters (R2P2) [8-10].

The proposed control strategy is based on keeping an eye on the switch's current and using it as feed-back [11]. Both switched-capacitor and quadratic boost are independently utilised in primary and sec-ondary circuits. A linked inductor connects the cir-cuit between them in order to get a large dc voltage gain [12].

The designed converter combines a voltage multi-plier circuit using coupled-inductor technology with a conventional quadratic boost converter. The output voltage of the developed converter is larger than that of the conventional QBC for the same duty cycle and input voltage, and it even reduces the voltage stress on the power device [13]. When an inductor is linked to the converter, the purposeful inrush current ripple is reduced.

Like micro-inverters, two dc to dc QBC designs for voltage magnifying operations combine the step-up capabilities of the quadratic boost converter and the tapped inductor. As a result, considerable step-up voltage gain may be attained at a reduced duty ratio [14]. Inside a quadratic boost converter with high dc gains, the controller features an inner sliding loop built using sliding-mode control, where the sliding face is set for the input inductor current. An external loop that responds to output voltage ripples uses a proportional-integral compensator to change the sliding face's current reference value [15].

A grid-interactive inverter controlled by fuzzy PI is developed and implemented. The proportional and integral gains are tuned by the fuzzy logic controller (FLC) for desirable operating point of the system [16]. Fuzzy logic controller system exhibits fast and smooth response with two techniques such as scalar controller Field oriented control and dynamic per-formance at a change in speed and transfer condi-tions were observed to be high [17-18].

In order to interact with inverters while serving AC loads or networks, MPPT with PV enabled dc-to-dc converters. The yield voltage profile, the revers-ing disasters, the soundness issue, and its total har-monic distortion (THD) were clear indicators for the inverter's demonstration. When the location of the inverter and the exchanging procedures were care-fully chosen, the THD of the inverter was greatly reduced [19]. A few exchanging methods analyzed in the research stage and the procedures posse's bene-fits and faults. The sinusoidal pulse width modula-tion (SPWM) method is the actual easiest and best one [20].

As of late, there had been an extensive incre-ment in the significance of staggered inverters, since they don't depend on only two degrees of voltage to make an AC signal. Then again, unique voltage lev-els were consolidated to one another subsequent in a smoother ventured waveform with less dv/dt and lower THD. There were a few sorts of geographies of a MLI to create a ventured waveform, including im-partial braced diode MLI, flying capacitor-MLI, etc. The natural quality force yield of MLI had pulled in analysts to investigate new geographies in MLI [21–24]. Among all MLI geographies, the reverse voltage geography MLI (RVT MLI) was popular in the re-search field for its decreased switch tally. This spe-cific geography was entirely viable with dispersed sources, for example, PV, energy unit and so on, as the wellsprings of medium force can be effortlessly fell to establish a higher limit inverter [25].

2. METHOD

GAP IN THE RESEARCH

The above-mentioned literature does not pro-vide comparable results for Optimization of Effi-ciency using output current THD minimization and loss minimization of QBCMLI-IM systems using FOPID-FOPID and FLC-FLC controllers. This work compares FOPID-FOPID and FLC-FLC-controlled QBCMLIS

2.1. Quadratic-Boost Converter-concept

The Quadratic Boost Converter is a second stage dc-dc support converter that can generate dc voltage. The yield voltage of QBC is constantly greater than the input voltage. The condition can be used to cal-culate the subsequent yield voltage.

$$V_{OUT} = \frac{V_{IN}}{(1-D)^2} \tag{1}$$

The Quadratic Boost Converter circuit com-prises of MOSFETs(Q) as switches, inductors-(L), diodes-(D), capacitors-(C) & resistors-(R) as bur-dens. The circuit activity depends on supposition that, the Q switch remains ideal in activity while, capacitors C1&C2 are thought to exist enormous thus voltage through capacitors VC1&VC2 is practi-cally steady during the changing cycle.

The inrush current in the MOSFET is resolved uti-lizing condition (2), where PG is the force at the gate which is dictated by the oscillator recurrence of 31kHz (from the datasheet) and Capacitor 380 mi-crofarads. While VGS is the source–gate voltage (VG) duplicated by the level of duty cycle (D).

$$I_G = \frac{P_G}{V_G} \tag{2}$$

Where,

$$P_G = F_S Q_G V_{GS} = V_G D \tag{3}$$

It is 2nd stage dc to dc support converter that ca-pacities to build dc voltage. QBC has a yield voltage that is consistently more noteworthy than the source voltage. The subsequent yield voltage can be deter-mined by the relation given in equation (4)

$$V_{out} = \frac{V_{in}}{(1-D)^2} \tag{4}$$

2.2. Fractional Order PID-Control

Engineers and mechanical specialists have often sought to replace the ordinary PID controller with a more convincing one. In any event, the PID-controller remains the most famous due to its sim-plicity and lack of need for regulator boundary clari-fication. Very recently, there has been an expansion of the conventional PID controller by subscribing the solicitations of the auxiliary and critical portions to any self-emphatic real number rather than settling those solicitations to one. Podlubny was the first to introduce the FOPID controller.Fig 2 shows FOPID control structure. Trade limit of a FOPID controller shows,

$$T_i C_{FOPID}(s) = Kp + \frac{K_i}{S_\lambda} + K_d S_\mu \tag{5}$$

Where λ - order of an integral part, μ – the order of the derivative part, KP, KI & KD – controller con-stants (as in traditional PID-controller).

2.3. Fuzzy Logic Control System

Figure 1 represents a basic Control System Using Fuzzy Logic. The FLC system comprises 2 inputs, i.e., error and change in error is determined when the output signal is compared to the input reference sig-nal. The phrase "change in error" refers to how this mistake is quantified in relation to time T. Fuzzifi-cation, inference mechanisms, and DE fuzzification are the three components of the fuzzy logic control-ler and are described in depth. Fuzzy rules, which are established by the fuzzy controller designer, are used by the controller to determine what would be the output when these inputs are supplied to FLC. Like this, the FLC output is provided to the machine or motor after processing.

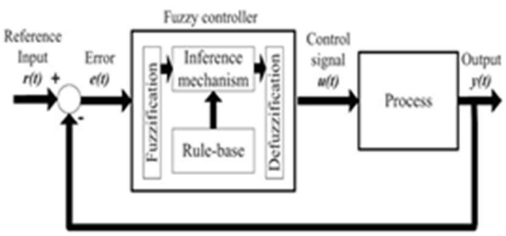

Fig 1. Control System Using Fuzzy Logic.

Control System Using Fuzzy Logic components

Three specific stages in FLC systems

Fuzzification: This stage incorporates membership functions and labels. According to a user-defined chart, FLC converts input data or variable data into a fuzzy membership function, such as a change in temperature or motor speed, and assigns the grade of the relevant data value from 0 to 1. Various contours might be considered for membership functions such as S, H, Z, π, Gaussian, etc.

Inference Mechanism: It is an absolute design that determines closure solutions using knowledge-based and answers from users.

DE- fuzzification: In this process a unique element is extracted from clustered output of fuzzy logic controller. De-fuzzification is perceived by a deci-sion-making algorithm which opts best crisp values based on fuzzy set.

3. FINAL STAGE ILLUSTRATION OF PROPOSED QBC-MLIS

Figure 2 describes block anatomy of Quadratic-Boost Converter with Multilevel-inverter. Block structure of closed-loop QBC-MLIS system using FOPID-FOPID/FLC-FLC control QBMLIIM appears in Figure 3. The IM speed is compared with refer-ence-speed. The flaw is pragmatic to the speed FOPID/FL-controller. The yield of FOPID-1 is ap-plied as the reference current. Iref is weighed with Iact to get error-current. This flaw is pragmatic for cur-rent-FOPID-controller. Thus, comparator updates the PW applied to QBC of QBMLIM.

4. SIMULATION RESULTS AND DISCUSSION

4.1. Closed loop FOPID-FOPID controlled QBC-MLIS

Figure 4 is delineating the Circuit diagram of closed loop FOPID-FOPID controlled QBC-MLIS. Figure5a and 5b delineate output voltage and current waveform of three phase inverter. Figure 5c. deline-ates the Output current THD with FOPID and its result is 5.93%.

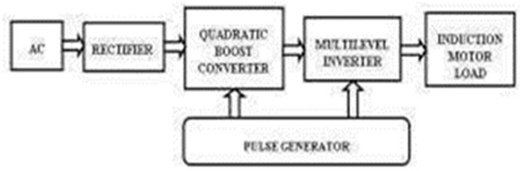

Fig 2. Schematic drawing of designed QBMLIIM FOPID/FLC

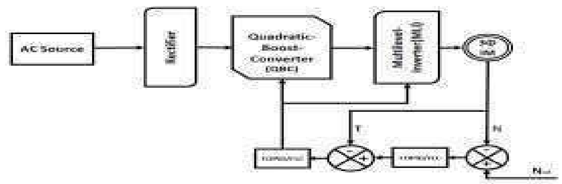

Fig 3. Schematic drawing of closed loop using QBMLIIM system

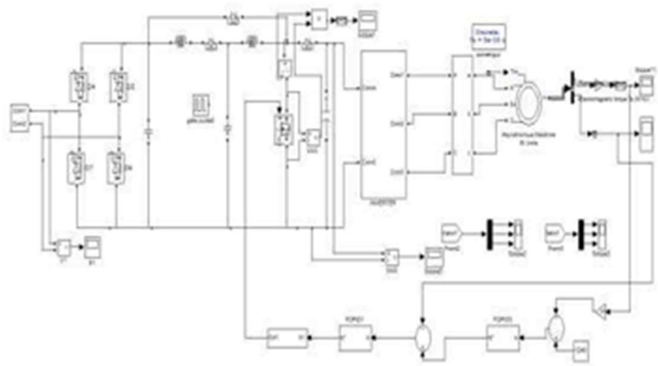

Fig 4. Closed loop FOPID-FOPID controlled QBC-MLIS.

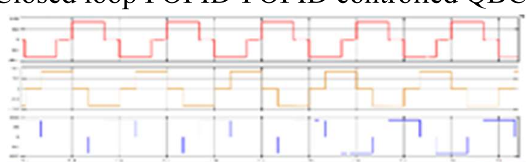

Fig 5a. Output Voltage

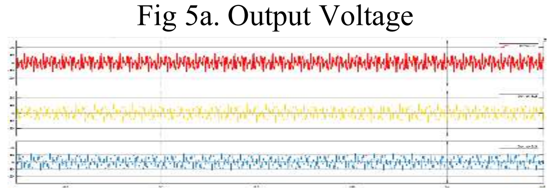

Fig 5b. Output Current of Closed Loop FOPID-FOPID

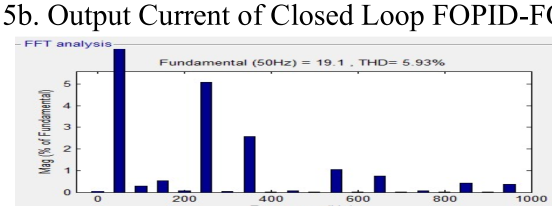

Fig 5c. Schematic drawing of designed QBMLIIM FOPID/FLC

4.2. Closed loop FLC controlled QBC-MLIS

Figure 6 is delineating the Circuit diagram of closed loop FLC-FLC controlled QBC-MLIS.FLC is used to handle the nonlinearity of IM and switches. Fig 7a and 7b delineate output voltage and current waveform of three phase inverter. Figure 7c deline-ates the Output current THD and its value is 5.32%.

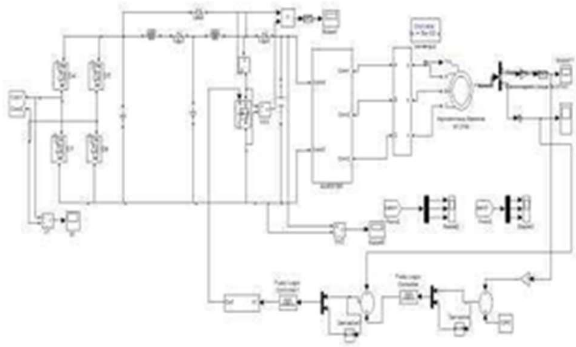

Fig 6. Closed loop FLC-FLC controlled QBC-MLIS.

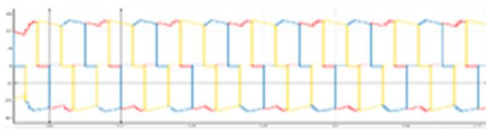

Fig 7a. Output Voltage

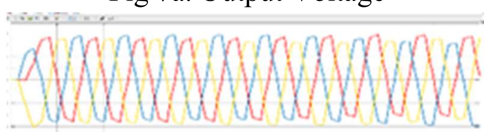

Fig 7b. Output current of Closed loop FLC-FLC controlled QBC-MLIS.

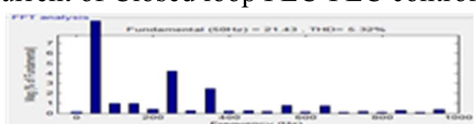

Fig 7c. Output current THD

Fuzzy logic is a type of logic that's also similar to human thought. The approach demonstrates human decision-making, which encompasses all possibili-ties between both the digital values either true or false. Fuzzy logic (FL) is beneficial, even if it does not provide precise reasoning. It however, provide acceptable reasoning. The FL is separated into piec-es, each of which contains a module that converts system inputs into fuzzy sets. Another module that stores the user-supplied IF-THEN regulations. An interference engine that uses fuzzy inference on the inputs and IF-THEN rules to replicate the human reasoning process. Defuzzification is a method that converts the fuzzy set acquired by the interference engine into a crisp number. The membership func-tion is used to cope with ambiguous groups of varia-bles. The membership function allows you to graph-ically display a fuzzy set and quantify linguistic terms. Because complex membership functions do not contribute greater precision to the output, simple membership functions can be used. Among the nu-merous membership function shapes, such as trape-zoidal, singleton, and Gaussian, etc., triangular membership functions are the most relevant.

(i) Fuzzy Logic Controller:

Step 1: Define linguistic terminology and variables.

The original settings for the system were = 10 volts, = 5 volts, = 0.5 mH, and = 0.5 mF.

Very low, low, normal, high, very high voltage sources

Step 2: Create membership-related functions for them. The FLC is designed in this part to control the buck converter in a methodical manner. The mistake speed (E) and the derivation of error speed (D) are the two input signals for the planned FLC (DE). FLC generates one output, which is the duty cycle of the power converter, using such input signals. The membership function for input variable E, output duty cycle Vo, and input variable DE is shown in Figure 8, 9, and 10.

Step 3: Create rules for the knowledge base, make a matrix of target and expected values, which you'll use to build the IFTHEN-ELSE rules. The set of knowledge-based rules established is shown in Table 1. The fuzzy rule includes 25 rules in total because one input signal contains five variables. The rules are shown in three dimensions in Figure 11.

Step 4: Get a fuzzily valued value, Rules are evalu-ated using the fuzzy set operation. OR & AND are represented by the operations Max and Min. To gen-erate a final outcome, combine the findings of all evaluations. As a result, the value is a little unclear. Defuzzification is the 5th step. For the output varia-ble, it is carried done using a membership function. The value is used to harmonize the FLC's output and output values.

Membership functions are plotted out as shown be-low:

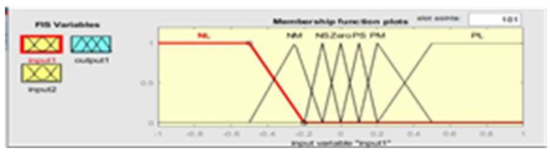

Figure 8: Membership Function of input (error)

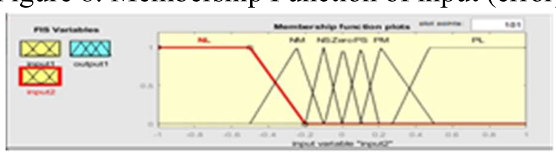

Figure 9: Membership Function of input (change in error)

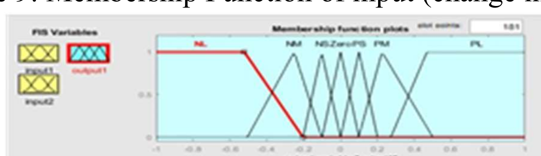

Fig 10: Membership function for output duty cycle

Fig 11. Rule View of Fuzzy Controller

Table 1
Knowledge-based rules

E/ΔE	NL	NM	NS	ZERO	PS	PS	PL
NL	NL	NL	NM	NM	NS	ZERO	ZERO
NM	NL	NM	NM	NS	ZERO	PS	PS
NS	NM	NM	NS	ZERO	PS	PS	PM
ZERO	NM	NS	NS	ZERO	PS	PM	PM
PS	NM	NS	ZERO	PS	PM	PM	PL
PM	NS	NS	ZERO	PS	PM	PL	PL
PL	NS	ZERO	PS	PM	PL	PL	PL

NL – trapmf- [-1.7 -1.06 -0.5 -0.2]
NM-trimf- [-0.5 -0.251 -0.1]
NS-trimf- [-0.198 -0.1 0]
Zero-trimf- [-0.1 0 0.1]
PS-trimf- [0 0.1 0.2]
PM-trimf- [0.1 0.2 0.5]
PL-trapmf- [0.1 0.2 0.5]

*trapmf-Trapezoidal member function
**trimf-Triangular member function

5. MOTOR SPEED RESPONSE COMPARISON OF CLOSED-LOOP FOPID-FOPID AND FLC- FLC CONTROLLED QBC-MLIS

Comparing Motor speeds of closed-loop- FOPID-FOPID and FLC-FLC – controlled QBC-MLIS wave-forms are delineated in Figure 12 & values are 1100rpm and 1200rpm. Comparing Motor torques of closed-loop- FOPIDFOPID and FLC-FLC – con-trolled QBC-MLIS waveforms are delineated in Fig-ure 13 & values are 10N-m and 5N-m with FOPID and FLC respectively.

Figure 14 & 15 represents the Bar Chart of Time Domain Parameters for motor speed and motor torque using closed-loop FOPID-FOPID and FLC-FLC controlled QBC-MLIS respectively. Compari-son of Time Domain Parameters for motor speed is given in Table II. By using closed-loop FLC-FLC controlled QBC-MLIS 'rise time' is lessened from 1.52 Sec to 0.58 Sec; 'Settling-time' is lessened from 1.59 Sec to 0.62 Sec; 'peak-time' is lessened from 1.54 Sec to 0.60 Sec; 'Steady-state error' is lessened from 1.25 RPM to 0.20 RPM.

A comparison of Time Domain Parameters for motor torque is given in Table III. By using closed-loop FLC-FLC controlled QBC-MLIS 'motor toque rise-time is lessened from 1.53 Sec to 1.50 Sec; 'Set-tling-time' is lessened from 1.70 Sec to 1.52 Sec; 'peak-time' is lessened from 1.58 Sec to 1.51 Sec; 'Steady-state error' is lessened from 0.78 N-m to 0.12 Nm.

A comparison of output current and switching losses for the closed loop FOPID-FOPID and FLC-FLC controlled QBCMLIS are given in Table IV. By using closed-loop FLC-FLC controlled QBCMLIS 'output current THD' is lessened from 5.93% to 5.32%; 'losses' are reduced from 15.9W to12.32W. The present work deals with investigations on loss minimization of FLC-FLC controlled QBCMLIIM system.

Table 2
. Comparison of Time Domain Parameters (motor speed) with FLC and FOPID

Controller	Rise time(s)	Peak tome(s)	Settling time(s)	Steady state error(rpm)
FOPID-FOPID	1.52	1.54	1.59	1.25
FLC-FLC	0.58	0.60	0.62	0.20

Table 3
. Comparison of Time Domain Parameters (motor torque) with FLC and FOPID

Controller	Rise time(s)	Peak tome(s)	Settling time(s)	Steady state error(rpm)
FOPID-FOPID	1.53	1.58	1.70	0.78
FLC-FLC	1.50	1.51	1.52	0.12

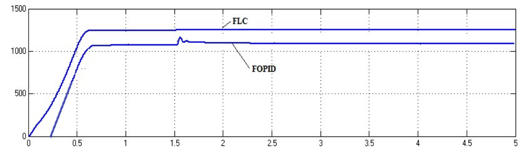

Fig 12. Motor speed with FLC and FOPID controllers

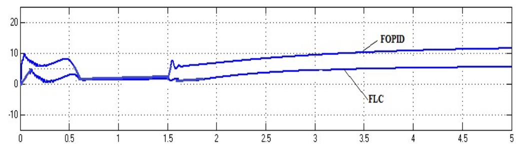

Fig 13. Motor Torque with FLC and FOPID Controllers

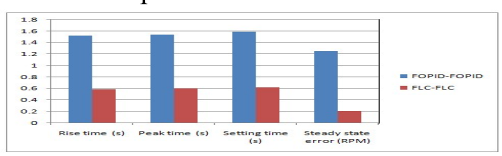

Fig 14. Bar Chart of motor speed

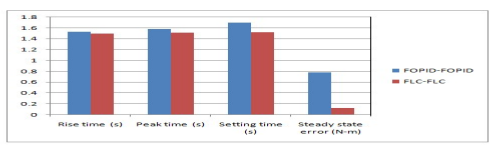

Figure 15. Bar Char for motor torque

Table 4

. Comparison of output current THD and losses

Controller	Output current THD	Losses(W)
FOPID-FOPID	5.93	15.9
FLC-FLC	5.32	12.32

6. CONCLUSION

MAT-Lab Simulink platform was used to model and simulate the loss reduction of the closed loop QBCMLIS system with the FOPID-FOPID and FLC-FLC controllers. The simulation outcomes of 'loss minimization in a closed-loop QBC-MLIS sys-tem with FOPID-FOPID and FLC-FLC are presented. By using closed-loop FLC-FLC controlled QBCMLIS, output current THD is reduced from 5.93% to 5.32%, and losses are reduced from 15.9Wto12.32W. Hence, the outcome represents that the closed loop FLC-FLC controlled QBC-MLIS is superior to closed loop FOPID-FOPID controlled QBCMLIS. The disadvantage of QBC-MLIS is the need for large-passive components. The recent work deals with investigations on loss minimization of FLC-FLC controlled QBCMLIIM system. The re-search on model predictive controlled QBCMLIIMS-system work will be carried out in future analyses.

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