Control System Design and the Power Management of MEFADEC Assembled on More-Electric Aircraft

Mingming Yin
AECC Aero-engine Control System Institute, Wuxi, China
miya_522@163.com

Serhiy Bozhko
University of Nottingham Ningbo Campus, Ningbo, China
serhiy.bozhko@nottingham.edu.cn

Taike Yao
AECC Aero-engine Control System Institute, Wuxi, China
taikeyao@163.com

Chengxin You
AECC Aero-engine Control System Institute, Wuxi, China
ycx0910@sina.com

***Abstract*—This paper deals with a novel control system design of More Electric Full Authorized Digital Electronic Control (MEFADEC) on the more electric aircraft. On the base of the analysis of the power management of MEFADEC system, the power of the more electric aircraft is also the vital platform to be considered. The definition of microgrid is introduced in the power management of the MEFADEC. The control law of the MEFADEC is the main course of this paper and some simulations are done to verify the design of the control system using Matlab/Simulink. The paper concludes that a closed loop speed control law of MEFADEC could meet the requirements of the original purpose and the outcome of the simulations have confirmed this. Some further research of the control of MEFADEC are needed to be done and even some practical experiments should get involved in this institution in the future.**

***Keywords*—MEA, MEFADEC, control system, closed loop, micro-grid, Matlab simulation**

I. INTRODUCTION

As more efficiency and more environmental-friendliness are the trends of the design of next generation aircrafts, traditional systems such as hydraulic system, mechanical system and pneumatic system inevitably need to be replaced by the new systems which are electrically-powered. Electric systems typically have the advantages of being more efficient hence greener than the traditional systems of the aircraft. The substituted old-fashioned systems transform into electric systems which include many generators and AC/DC loads to achieve the demand requirements of the aircraft. The increasing amounts of the electronic accessories require more electric power than previous platforms which means that the power management of the electric system is more important for the new technology application [1] , [2]. More-electric aircraft is a driver for development of new technologies for energy generation, storage and conversion systems. There are yet many associated challenges in MEA development [3].

The newer commercial aircrafts like Boeing-787 and broad-cabin A380 eliminate the integrated drive generator (IDG). The IDG is used to transfer the variable speed to constant speed of the aircraft engine by some mechanical accessories. Constant voltage and constant frequency system is provided to power the aircraft bus. Now the aircrafts use the new technology to change the system from constant voltage constant frequency system to variable voltage and variable frequency system through a gearbox. The frequency can vary from around 350 to 800Hz [4]. The variable voltage variable frequency system provides the power to different AC or DC loads to fulfill different demanded functions like actuators and sensors uses [5]. The loads can be divided into 28VDC and 270VDC and 115VAC voltage levels to achieve the required functions. Many large aircrafts combine the accessories of flight control subsystem, avionics system and deicing subsystem [6]. The eliminated traditional systems are substituted by the generators connected to the aircraft engine to generate the power needed by the functional layers. The electric power of the aircraft irrupted than before. The management of the electric systems is vital to be considered [7], [8].

II. POWER MANAGEMENT OF MEFADEC

Most aircraft engines benefit from electronic engine control (EEC) technologies, the EEC system can make the engine run at higher efficiency atmosphere, in the operation environment of the control system, only input evaluating needs to be done and the sensors could tell the valuable inputs that you want to value. As the more electric aircrafts gradually abandon the mechanical systems, More Electric Full Authority Digital Engine

Control (MEFADEC) does the same way, the reduction use of the mechanical system makes the longer service intervals possible and cut the cost of the engine maintenance and to achieve higher reliability. The utilization of the digital technology means that the computer takes over the control of the engine through EEC. FADEC combines throttle, prop and mixture

controls into one single control unit which improves the fuel economy of the engine operation. Now the FADEC is always assembled on the surface of the aircraft engine. For MEFADEC, it will become an internal part of the engine which means that the engine will become a more electric engine and will become more efficient and more reliable with fewer fuel assumption. There are some disadvantages of traditional FADEC like no manual override control, and certain speed limits in all circumstances. These problems will be solved in MEFADEC, it is a revolution for more electric aircraft design [10], [9].

In recent years, dc micro-grids have been increasingly used in automotive applications, including aerospace, for example aircraft control. The generators used on the more electric aircraft have various roles to play, to start the engine of the aircraft or generate the power as a machine. Detailed control design of the MEFADEC with multiple channels and massive loads has been performed, the steady-state operation power performance is elaborated. There are some typical loads in a dc microgrid, such as voltage-controlled dc to dc converters and speed-controlled generators which operate the system as constant power loads [11]. The basis of the power management of MEFADEC is established in Fig 1. The schematic diagram simply shows how the system works.

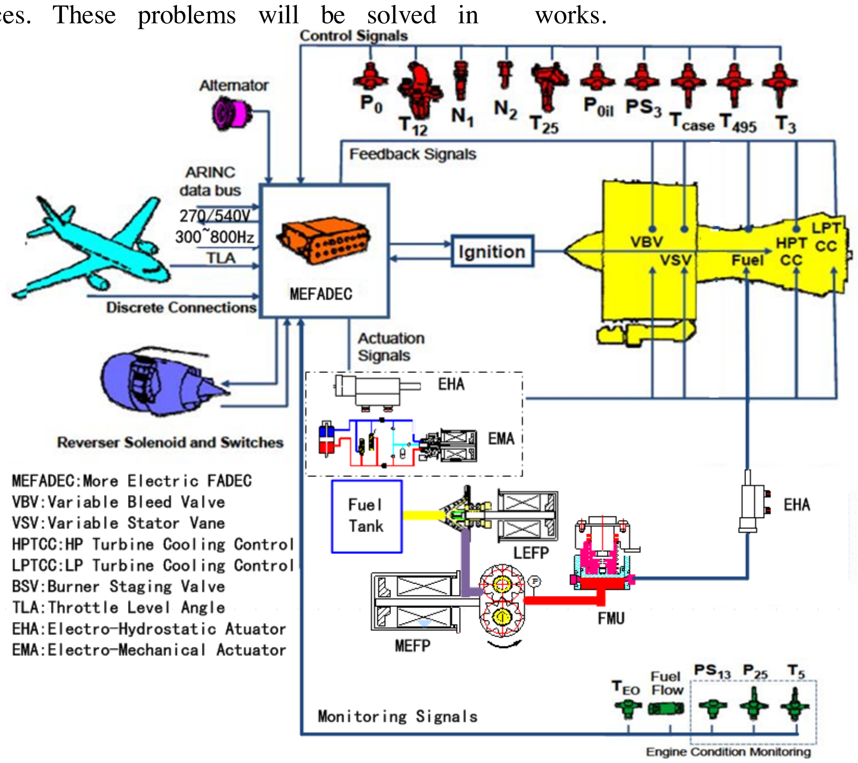

Fig 1 The Schematic Diagram of MEFADEC

III. Control Law of MEFADEC

Typically, in an EEC control system, the system has two layers, the outer loop and the inner loop. The inner loop is called fuel-flow loop. This loop utilized the fuel pillow to monitor the fuel-flow of the engine tank. The outer loop is the speed loop, when the pilot moves the PLA (throttle level), the engine will run into different operation points. There are mountains of control algorithms in the control system design, for aero-engine, it is generally about the control design of fuel oil supply and the speed of engine.

Via regression processing algorithm, a position PI control method is proposed to modify the control loop. First, set the demand fuel flow value, and add the error value of fuel flow. The inputs consist of the two mentioned variables and the states of the engine could be derived

from the control block of the engine model. In some complicated scenarios, there are channels to be selected as the fuel flow demands, in different engine states, alternations are made to be the optimum choice for the control system. It is more intelligent for an electric control system, as the system will reasonably make the choice with all the circumstances to be considered.

Furthermore, the diagram in Fig 1 is an example configuration of the power flow in a MEFADEC, indicating how the inputs and outputs connected with each other and how the signals work in the system. After calculating the power demand of the control system, taking into account actuators and generators, as well as loads like pumps and valves required by the system, a required power level is derived and the drawing achieves all the functions which are required by the control system. This is not just the modelling work, and half-physics experiments will also be involved in the future work. This paper makes it possible to reduce the integrated air bleed of the engine system using the electrical system instead.

Put the discussions of high temperature of the indispensable power electronics components like EHA and electric machines need and the faults tolerance aside of this initial study. The simulations will be employed for verification of derived results.

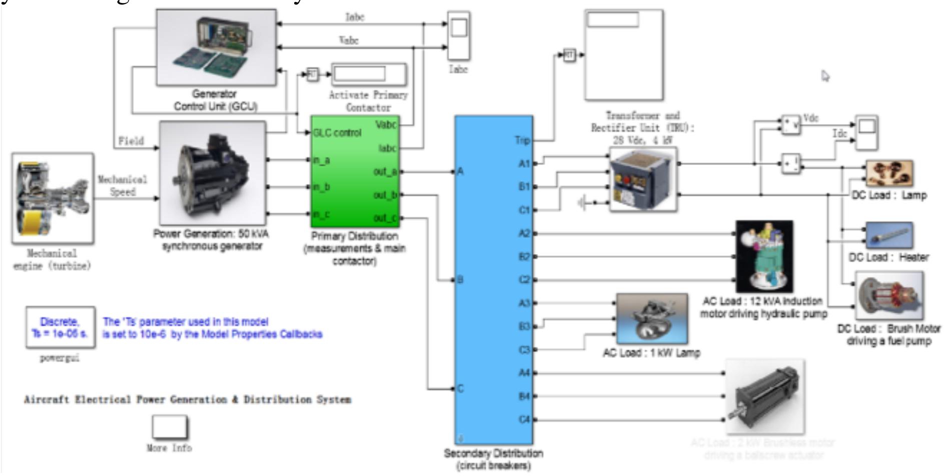

Fig 2 Control System Diagram in MATLAB

More electric fuel pump

More electric engine utilizes a motor to drive the fuel pump and change the motor speed to control the fuel flow. The fuel flow response and metering precision are depended on motor response character and fuel flow feedback precision. In order to improve the motor response, a direct drive motor is used on driving the fuel pump. The electric fuel pump controller receives the fuel control signal from engine digital controller, test the fuel flow through the fuel flow sensor feedback signal. According to the differential fuel flow between the control signal and the feedback signal, compare them to the actual operational condition，adjust the motor speed and fulfill the fuel flow control. The control diagram is shown in Fig 3.

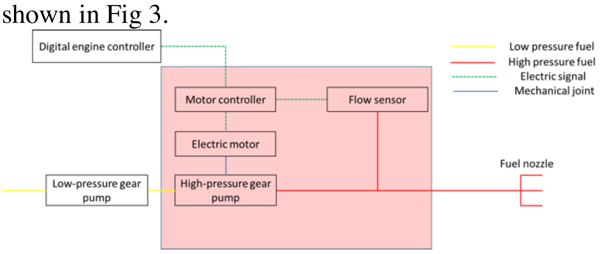

Fig 3 Control diagram of electric fuel pump

Motor control

The system applys current loop-speed loop-position loop triple loop control strategy, among it, current loop and speed loop adopt PI adjustment, position loop use P revision. Aiming to brushless direct current machine current feedback, the system could collect bus current or phase current, mostly, collection of bus current is used as the feedback to establish current loop.

As phase current is directly relative to machine torque, but bus current is differential to phase current, in order to assure bus current could reflect phase current precisely, sample time could be set as each PWM period valid time middle moment and remain, until update in the next PWM period. For current loop, generally choose proportion-integration adjustment as above said, fix the current loop as I type system. The parameters are shown in Table1.

Table1 Parameters of the motor control system

Name	Type	Value	Unit
Resistance	R	0.2	Ω
Power drive amplification factor	K_{PWM}	50	V
Motor winding inductance	L	0.3	mH
Equivalent moment of inertia	J_e	0.6×10-3	Kg×m2
Coefficient of viscous friction	B	0.0002	Nm/rad/s
Machine torque coefficient	K_m	0.286	Nm/A
Electromotive force coefficient	K_e	1.1	rad/s

Current loop consists of demand control, feedforward control and feedback control. The diagram shows the simulation outcome of the control system.Position loop composes of demand control and feedback control. The diagram shows the step response of the simulation, which illustrates that the control system is stable as it is respected.

Without controller，the tf of the system will be :

$$G_i(s) = \frac{K_{PWM}}{R(\tau_i s+1)(\tau_{fi} s+1)}$$

The tf of controller of the system is：

$$C_i(s) = \frac{K_{pi}(T_{ii} s+1)}{T_{ii} s}$$

So finally, the open loop tf will become:

$$GC_i(s) = \frac{2500}{0.0002s^2 + s}$$

And the close loop tf will be:

$$TC_i(s) = \frac{0.5s + 2500}{0.0002s^2 + s + 2500}$$

About the procesure of building the control system is not going into details in this paper but the simulation outcome will be illustrated.

IV. SIMULATION AND VERIFICATION

Build the MEFADEC control system in the MATLAB as Fig 2 shows, the system divides into two distributions, primary distribution and the secondary distribution. All the pictures attached in the sub-models are not realistic but conceptual for schematic diagrams.

Aero-engine modeling

In this paper, the monitored engine model assumes a height of 26.5km, math number of 3.2, and the Table2 shows its linearized characteristics. There are many ways to identify an aero-engine; in the actual working operations the model of the engine is more complicated than the simulation model or half-physics platform, so in order to testify our control method could work, it is necessary to simplify the engine model into a linearized one，set the model as a linearized formula of $K_e/(T_e s+1)$ and the identification data is shown in Table2. As the model of engine identified, the proposed control object has been settled.

Step response

V(rpm)	FL(kg/h)	Ke	Te
70	322	0.03052	1.6629
72	389	0.02948	1.9201
74	432	0.08181	4.3520
76	460	0.06363	3.4428
78	492	0.03793	2.1817
80	529	0.03623	2.1930
82	582	0.03494	2.1743
84	639	0.02616	1.6783
86	704	0.02514	1.6756
88	782	0.00946	0.6522
90	866	0.00704	0.5567
92	1107	0.00523	0.4716
94	1427	0.00482	0.4687
96	1813	0.00375	0.3815
98	2242	0.00800	0.9399
100	2767	0.00849	1.1060

The position PI control algorithm is used in this study. The control structure is shown in Fig 4. The control system of the engine is shown in Fig 7. It demonstrated that there were two control layers, the inner fuel flow loop and the outer engine speed loop. The aero-engine has many characterizations to describe it, but according to the time and space limit, this paper choose engine relative speed N_2 as the control variable. and N_{2_dem} is the reference of the speed, L_{mf} is the fuel metering valve which shows the fuel flow of the system，W_f is the main fuel flow.

Table2 The linearized model data of one type aero-engine

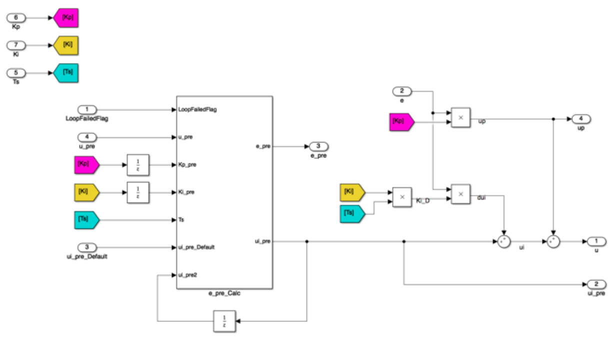

Fig 4 Control Strategy Structure of System

In order to verify the control system, first choose a stable operation point, like H (height) equals to 11, M (mach) equals to 0.8. A small step signal is given to the input, see the output in Fig. 5. The two upper lines show the engine rotate speed, the downside ones are for fuel flow, it is obviously that, either the N_2 and the N_{2dem} or the W_f and the W_{fdem} are mostly fit with each other. The system is stable.

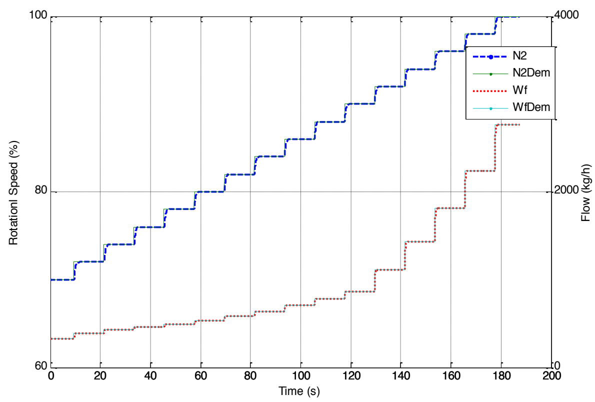

Fig 5 The step response of the engine speed of the control system

Acceleration and deceleration control

For a control system of an aero-engine, there are various of characterizations; In this paper, the speed of aero-engine rotor is chosen to be the controlled variable for the control system. Fig 6 demonstrates the acceleration and deceleration test of the control system. First, push the throttle level to maximum speed, which means the system approaches the acceleration period - the period last for 5s, during which the engine is stable at the maximum operating point. After 10s, the throttle level is put back to the idle engine state, and the engine goes the deceleration. At time 6s, the speed is limited by the acceleration, and for the last 2.5s the speed is limited by the deceleration and reaches a stable equilibrium point. The operation performance is good, as verified by simulations.

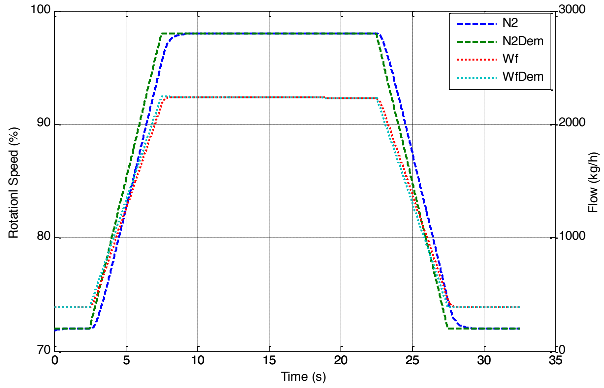

Fig 6 The diagram of acceleration and deceleration of the control system

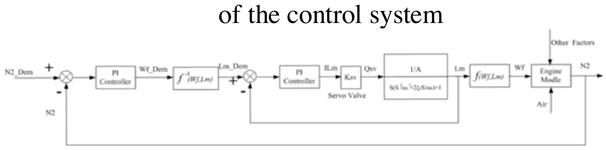

Fig 7 Control diagram of engine

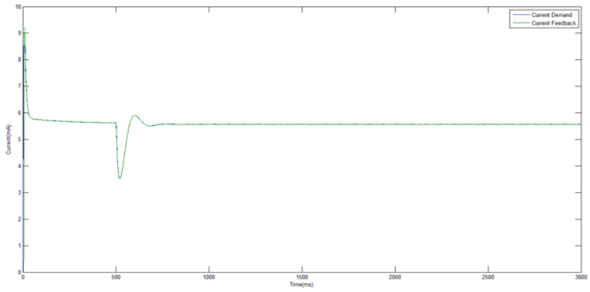

Fig 8 Current loop simulation outcome

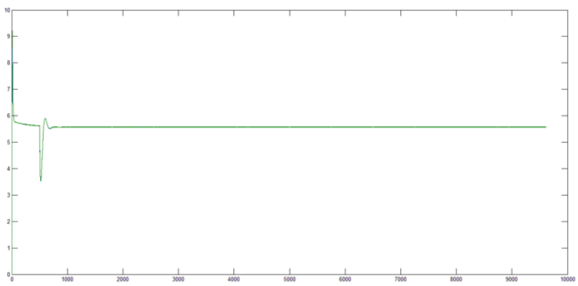

Fig 9 Position loop simulation outcome

V. Conclusions

The paper focuses on the control design of MEFADEC system which could be a new area of more electric aircraft application. The diagrams of accessories and models are provided, and after analysis the position control algorithm based on PI control is chosen. Set of simulations is completed to verify the control design of the MEFADEC system. There is a large number of elements to be considered and different engine operation mode and these vary a lot. This system is verified by the speed and fuel flow control simulation. As electric pump is used in the MEFADEC, this paper deals with the pump drive control and the machine control, including models establishing and doing some simulation. It illustrates that the simulation outcome meet the requirements and satisfy the system. Additional more-electric technologies need to be added to further studies to fulfill the MEFADEC application in future applications.

Acknowledgement

Thank you for Mr. Serhiy who found the novelty of this paper, thanks to Yao and You who inspire this work and give many good suggestions.

References

[1]. Mohd Tariq, Ali I. Maswood, Chandana Jayampathi Gajanayake, Amit Kumar Gupta, “Aircraft batteries: current trend towards more electric aircraft” IET Electrical Systems in Transportation (Volume:7, Issue:2, 6 2017).

[2]. Giampaolo Buticchi, Levy Costa, and Marco Liserre, “Improving System Efficiency for the More Electric Aircraft”, IEEE Industrial Electronics Magazine (Volume:11, Issue 3, Sep.2017).

[3]. Kamiar J. Karimi, PhD Senior Technical Fellow Boeing Company “Future Aircraft Power Systems Integration Challenges”

[4]. Bulent Sarlioglu, and Casey T. Morris, “More Electric Aircraft: Review, Challenges, and Opportunities for Commercial Transport Aircraft”, IEEE Transactions on Transportation Electrification (Volume:1, Issue:1, Jue.2015).

[5]. Zhuoran Zhang, Jincai Li, Ye Liu, Yanwu Xu, and Yangguang Yan, “Overview and Development of Variable Frequency AC Generators for More Electric Aircraft Generation System” , Chinese Journal of Electrical Engineering (Volume:3, Issue:2, September 2017).

[6]. Pat Wheeler and Serhiy Bozhko, “The More Electric Aircraft Technology and challenges” , IEEE Electrification Magazine (Volume:2, Issue:4, September 2014).

[7]. Fei Gao, Serhiy Bozhko, Alessandro Costabeber, Greg Asher, and Pat, “Control Design and Voltage Stability Analysis of a Droop-Controlled Electrical Power System for More Electric Aircraft” , IEEE Transaction on Industrial Electronics (Volume:64, Issue:12, Dec.2017).

[8]. Fei Gao, Serhiy Bozhko, Alessandro Costabeber, Chintan Patel, Pat Wheeler, Christopher Ian Hill, and Greg Asher , “Comparative Stability Analysis of Droop Control Approaches in Voltage-Source-Converter-Based DC Microgrids” , IEEE Transaction on Power Electronics (Volume:32, Issue:3, March 2017).

[9]. General aviation Joint Steering Committee Safety Enhancement Topic “Full Authority Digital Engine Control (FADEC)”

[10]. Nikhil Kumar C, Shravan Kumar Bachelor of Engineering (Computer Science and Engineering), REVA Institution of Technology and Management, Bengaluru, Karnataka, India.

[11]. F. Gao, X. Zheng, S. Bozhko, C. Hill, and G. Asher, “Modal analysis of a PMSG-based DC electrical power system in the more electric aircraft using eigenvalues sensitivity,” IEEE Trans. Transp. Electr.vol. 1, no. 1, pp. 65–76, Jun. 2015.

[12]. W. Wang and M. Barnes, “Power flow algorithms for multi-terminal VSCHVDC with droop control,” IEEE Trans. Power Syst., vol. 29, no. 4, pp. 1721–1730, Jul. 2014.