A Novel Distribution Automation involving Intelligent Electronic Devices as IUT

M. Sadeghi, M. Gholami

Abstract**—** A Novel Distribution Automation is the bonnie state of art, comprising the new architecture based on the flexible electrical network of component together with an open communication structure debate the Future Distribution Automation System. Intelligent Universal Transformer (IUT) comprises from power electronic base equipment in addition with traditional current transformer introducing as an Intelligent Equipment Devices (IED) for Advanced Distribution Automation (ADA) in forthcoming future. In contrast to ordinary transformer, IUT has full control compatibility as it has been considered for intelligent device. In this regards Fuzzy Logic Control (FLC) is an advanced method based on fuzzy logic concept (first issued by Lotfy Zadeh) emphasizes on fuzzy algorithms which are formulated by linguistically rules, employing expert knowledge. Model free system, nonlinearity, robustness and flexibility under parameter variations are the benefit advantages resulting from the fuzzy logic controllers. In this approach four layers IUT topology with the diverse services like DC voltage option, 400 HZ utility for communication, 120 and 240 V AC 60 HZ together with fuzzy logic controller have been considered for evolving the stability, reducing the uncertainty and enhancing the efficiency of whole system. Fuzzy logic control schemes are proposed for employing current source controllers in IGBT inverters at input stage and DC voltage control source in output stage. Real time voltage regulation, automatic sag correction, three-phase power from a single phase line, Harmonic Filtering, Flicker mitigation, options for energy storage , dynamic system monitoring and robustness under load disturbances are the resulting benefits contributed from IUT four layers topology and fuzzy logic controllers .

Keywords**—**Fuzzy Logic Controller, Intelligent Universal Transformer, Advanced Distribution Automation, Indigent Electronic Device

I. Introduction

ADA with the new methodology in control and management leads a gigantic revolution in distribution automation systems resulting in a full automatic monitoring and control. A flexible distribution automation evolving the real time operation and control, enrolling the new approach for exchanging the electrical energy, data and information in a dynamic manner among the consumers and system equipments.

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Re developed electrical construction and open communication architecture empowered each other to contribute the ADA topology Enumerated the many benefits as:

- Enhance the reliability for automation equipment
- Develop intelligent monitoring systems
- Improves efficiency and optimizing the system performance
- energy management systems in a wide area for All included optimization of generation compost, system safety, system demand, power flows and

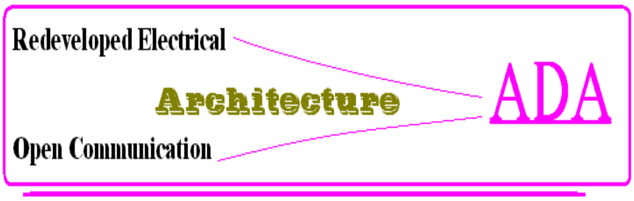

Fig. 1 ADA Basic architecture

ADA is the cornerstone for convenience integration in the moderated electrical technologies from the viewpoint of electrical system designers.

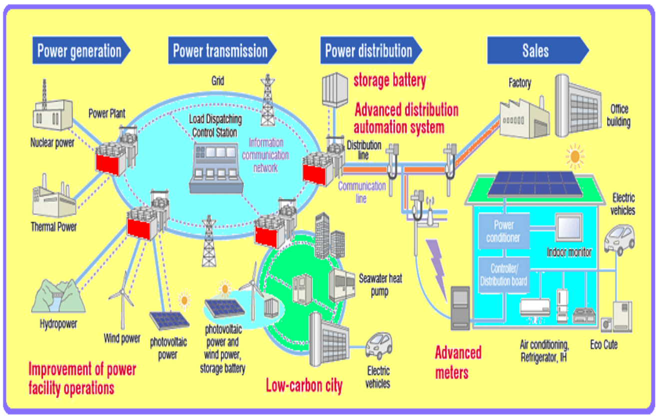

Fig. 2 Advanced Distribution Automation (ADA) in future Smart Power System

ADA is the foundation for contributing the distribution system in future. In this regards it will be included on new technologies utilization evolving the intelligent universal transformer, new sensors, new power-electronic controllers, switched capacitors, load management equipment, modern sag correction devices, voltage regulators and so on.

The new modern power electronic technologies [4], [6] motivate the creation of new generation of transformers as intelligent devices for Advanced Distribution Automation in future.

Network of intelligent electronic devices together with the redeveloped and flexible electrical architecture increasingly enhance the reliability and improves efficiency and functionality in distribution system and will comprise the forthcoming distribution automation as ADA [3], [5], [14].

Interoperability became true under the flexible electrical architecture. Regiment of electrical controllers and electrical equipment among the distribution system improved functionality, recover the performance, enhance the reliability and betterment the power quality employing an organized fashion.

IUT [7], [11-13], [17] is a basic resource enrolling a key point in ADA conceptual construction which is fundamental part in smart grid network.

IUT comprises from a high speed high voltage transformer [8-10], [15], AC/DC rectifiers and DC/AC inverters based on high speed low current power electronic elements. It is introduced in lieu of traditional distribution transformers with a great and divers benefits like DC voltage option, automatic sag correction, capability of regulating the voltage in real time operation, offering a various reliable power as 400Hz service, three-phase power service from a single phase line, dynamic system monitoring, Harmonic Filtering, Flicker mitigation, storage energy options and ability for storing the electrical energy which is a real revolution in today's distribution automation.

New construction based on high frequency transformer and low current solid-State devices comes to make considerable reduction in IUT weight and dimensions. HV oil free transformers usage causes the advantage of maintenance free equipment and also prevents from the Environmental oil pollution. Control ability in conjunction with input AC/DC converters and output DC/AC inverters in IUT topology leading the IUT as a full automated control and intelligent devices.

Tomorrow's transformers with the basic ADA over view and IUT four layers topology are described in the next section. Section III, will comprise the FLC modern controllers and control strategy. Section IV elucidates the simulation of FLC on four layers IUT topology in Matlab.

The last section evolving the conclusion and the prospective features of proposed FLC methodology.

II. TOMORROW'S TRANSFORMERS

A. *The Basic Concept*

ADA employs the novel moderated power electronic technologies stimulate creation of new advanced technologies. We discussed one the most important one which takes the critical key point in ADA as Intelligent Universal transformer (IUT).

IUT will comprise from a high voltage low current power electronic base transformer in spite of traditional distribution transformers.

At first, in the primary side converter, the input low frequency (60Hz) sine-wave voltage is converted to a square wave high frequency AC that will magnetically coupled to the secondary stage as the isolated high frequency voltage. Then at the secondary side, power converters will change these HF voltage to LF (60Hz) waveform .This occurs by synchronous operation of the primary and secondary side converters by 50% duty ratio modulating in the switches of HF square wave.

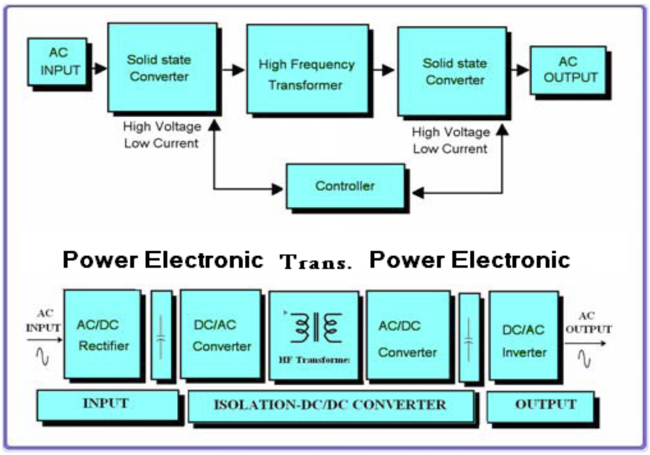

Fig. 3 IUT power electronic construction with full automated control capability

IUT communication interface is based on IEC 61850 as open communication standard for exchanging information and data which will be integrated by EPRI in the IEC-TC-57 for standardization of object model.

IUT evolving the numerous benefits and advantages as delivering new service option like automatic sag correction, DC voltage service, reliable diverse power as 400Hz service for using in communication, accessibility of three-phase power even from a single phase source line, availability on storing electrical energy, capability of voltage regulation in real time operation, Harmonic Filtering, Flicker mitigation, and dynamic system monitoring.

B. *Universal Transformer Topology*

There are several topologies which have been described for IUT. In this article we choose the four layer topology based on seven basic blocks evolving the multilevel rectifier and inverter, high frequency transformer and the four layers outputs comprising DC voltage, AC 400 HZ and two main 240 V AC 60 HZ.

In the first stage the multilevel rectifier (1r) and Multilevel Inverter (1i), rectify the input AC voltage and convert it to HF- HV square wave. DC voltage produced by the second stage, the DC bus capacitors (2). HF transformer (3) takes the task of isolating inputs from outputs. Rectifiers and filters (4), make the DC output voltages. The fifth stage is a main inverter (5), assigns 120/240-V 60-Hz output.

400 Hz output service developed by an auxiliary inverter, DC/DC converter (7), takes the 48-VDC output. In this topology, IUT defines divers outputs services (5, 6 and 7).

As it is clear IUT can be developed to deliver DC output voltages in any desired level, AC voltages with different arbitrary frequencies which were impossible in the state of traditional transformers.

On the other hand as in IUT the transferring ratio is unit so the weight and physical dimension in IUT face with the sizable reduction as it could be considered with oil free technologies which in turn yield to maintenance free resultant causing to pollution elimination and more clean environment.

The transformer is entirely considered as an energy transformation device so that the instantaneous power across the input terminals is equal to the output terminals.

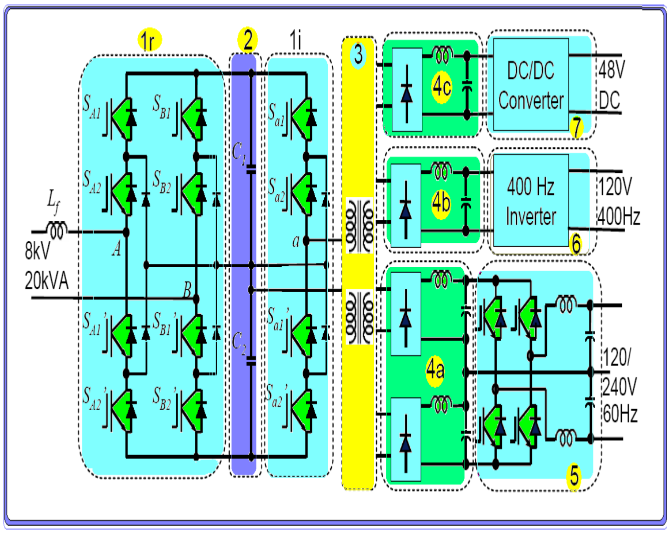

Fig. 4 IUT main topology evolving seven individual blocks

III. FLC Modern Controllers

Fuzzy logic controllers are the powerful control method has been proposed first by Lotfi A. Zadeh at Berkeley in 1965 paper. It is presented as a control methodology for processing data by allowing partial set membership function in compare to the crisp values. It applied to control systems on 70's as the computer capability was insufficient before.

The fuzzy logic controllers could be progressed under noisy, imprecise input. So they are really more effective and easier to implement.

Fuzzy logic controllers are the non-linear controllers with a widespread application on the unknown, linear and non linear, simple and complex systems [26], [30].

It controls the systems with ought any information regarding the transfer function among the input and output variables [25], [27], [29].

It is a human base rules in sentences for producing the control strategy based on rule equations which comes from the human experiences [1], [2], [16], [28].

In FLC the input variables mapped by sets of membership functions known as "fuzzy sets".

Fuzzy set comprises from a membership function which could be defined by parameters. The value between 0 and 1 reveals a degree of membership to the fuzzy set. The process in which the crisp input values convert to a fuzzy values is nominated as "fuzzification".

The FLC basic operation is constructed from a fuzzy control rules utilizing the linguistic values of fuzzy sets in general for the error (Ai), the change of error (Bj) and control action (Cij):

$$\text{If } e \in Ai \text{ and } \Delta e \in Bj \text{ then } u \in Cij \qquad (1)$$

Results are mapped into a membership functions in which the results are combined to give a specific ("crisp") answer controlling the output variable. this step is known as "defuzzification".

The fuzzy operations and rule-based "inference" colaborated to describe a "fuzzy expert system".

Traditional control systems are structured on mathematical models which employing differential equations comprising the system reaction to the inputs.

Fuzzy logic controllers comprising from an input stage, a processing stage and an output stage. In the input stage the inputs from sensors, switches,… are mapped to the proper membership functions. In the processing stage each appropriate rule will be invoked and a result has been generated for each of them, at last the results will be combined to form the rules. in the output stage the combined result will be assigned with the special control value.

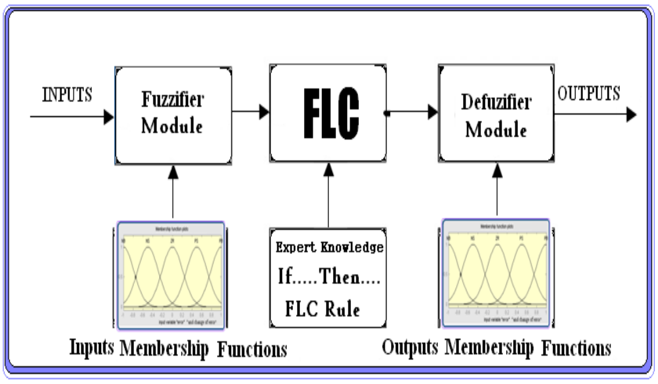

Fig. 5 FLC basic module including Fuzzifier, Defuzifier and Fuzzy sets

A. Control Strategy

Control strategy is based on Fuzzy logic controllers in input and output stages. In the primary stage, IUT is connected directly to the smart grid. For eliminating the harmonic distortion, the input current and voltage should be both sinusoidal and in phase with each other these could be achieved by Fuzzy Logic Controllers.

In the input stag, FLC in AC/DC converters senses the input current in IUT and compare it from the reference current, any deviation from the reference is mentioned as error. Error and change of error are considered as inputs of FLC.

FLC enrolls the duty of control for preventing any disturbances of input from the grid.

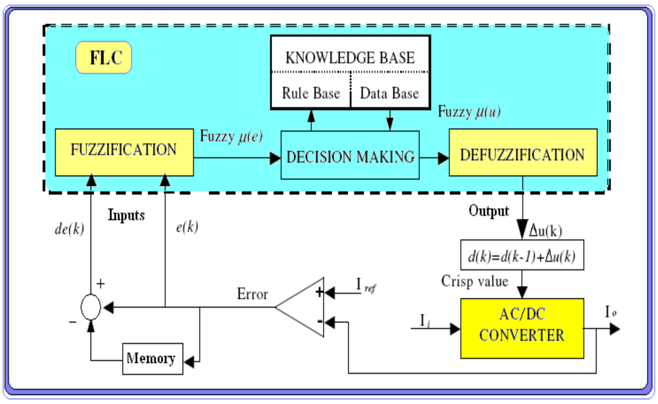

Fig. 6 Current source controller comprising from a Fuzzy logic controller for AC/DC converter in Input stage

In the output stage the FLC take the role of keeping the output voltage constant in the condition of load disturbances figure 7.

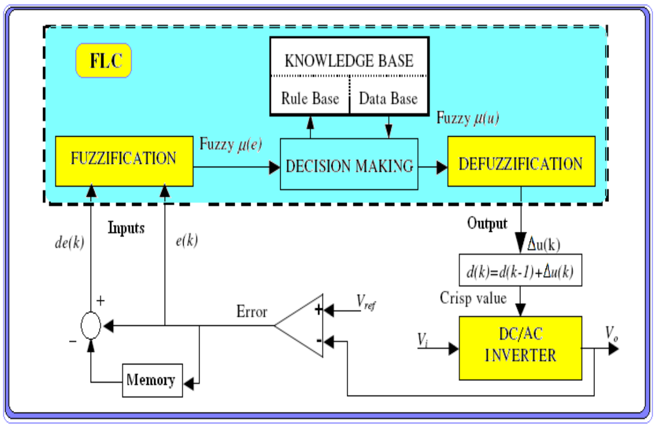

Fig. 7 voltage source controller comprising from a Fuzzy logic controller for DC/AC inverter for controlling the outputs voltages (48V DC, two 240V AC, 120V AC)

Membership functions for error and change of error are illustrated in figure 8.

Error and change of error are the inputs factors for FLC, FLC singletons and the numerical values assessment converts them into seven linguistic variables as PL (Positive Large), PM (Positive Medium), PS (Positive Small), ZE (Zero), NL (Negative Large), NM (Negative Medium) and NS (Negative Small).

fuzzification module determine the membership function degree of each linguistic variable for the error and change of error in each real time cycle .

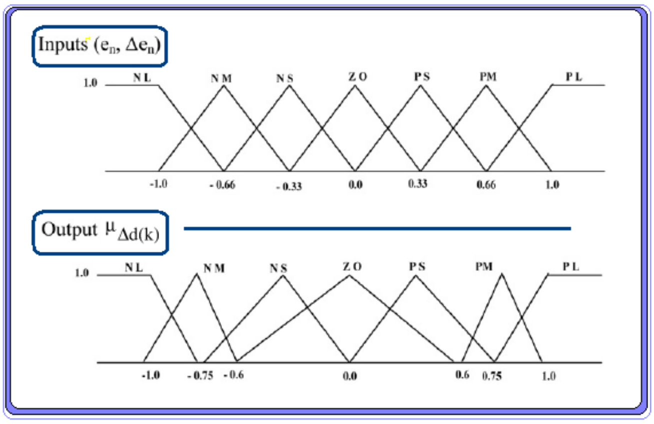

Fig. 8 Seven membership functions for error, seven member ship functions for change of error and seven membership functions for duty cycle or change of output

49 fuzzy rules have been created by seven linguistic variables for each of error and change of error demonstrated as a FLC rule base on figure 9.

Control

e \ Δe	NL	NM	NS	ZR	PS	PM	PL
NL	NL	NL	NL	NL	NL	NL	NL
NM	NL	NL	NM	NM	NS	NS	NS
NS	NL	NM	NM	NS	NS	NS	ZR
ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR
PS	ZR	PS	PS	PS	PM	PM	PL
PM	PS	PS	PS	PM	PM	PL	PL
PL	PL	PL	PL	PL	PL	PL	PL

Fig. 9 control strategy based on 49 Fuzzy controls Rule with combination of seven error states multiplying with seven change of error states

The weighting factor (w_i) is obtained acc. To the following equation by min fuzzy implication of Mamdani rule.

$$w_i = \min\{ \mu e(e), \mu ce(ce) \} \qquad (2)$$

the inferred output u_i being achieved by

$$u_i = w_i \cdot y_i. \qquad (3)$$

y_i is the centroid of membership function which describe the ith rule of output variable.

Weighted average is a method we considered here as a defuzzification procedure for reaching a unique control. This fashion is preferred because it deal with a Simple calculations according to the following equation:

$$\Delta d(k) = \frac{\Sigma_{i=1}^{4} u_i}{\Sigma_{i=1}^{4} w_i} \qquad (4)$$

$$d(k) = d(k-1) + \Delta d(k) \quad (5)$$

This is the real time fuzzy output producing y the FLC in each cycle. The crisp value depends on the previous control operator d(k-1) updated by variation in control module $\Delta d(k)$.

In case of enormous or slight changes in load or agile mutation in input current of IUT the FLC (Fuzzy Logic Control) response is quite nonlinear, as FLC should compensate the positive large error or negative small one for completing the control procedure.

IV. Simulation In Matlab

Fig 10 demonstrates IUT with four layers topology circuit diagram and FLCs. At first IGBT rectifiers, rectify and convert the input voltage to DC.

FLC in input stage sense the input current, compare it from reference current and keeps it constant.

DC/AC Inverters at second stage produce a HF square wave.

On the other side of high frequency transformer, four Voltages hold constant by four Fuzzy Logic Controllers in output stage.

PWM DC/DC converter produces the 48V DC from the first DC buss. This voltage must contain fixed under load disturbances.

A Fuzzy Logic Controller measures the output voltage, compares it to desired voltage 48V DC and makes it constant by voltage control (voltage source control).

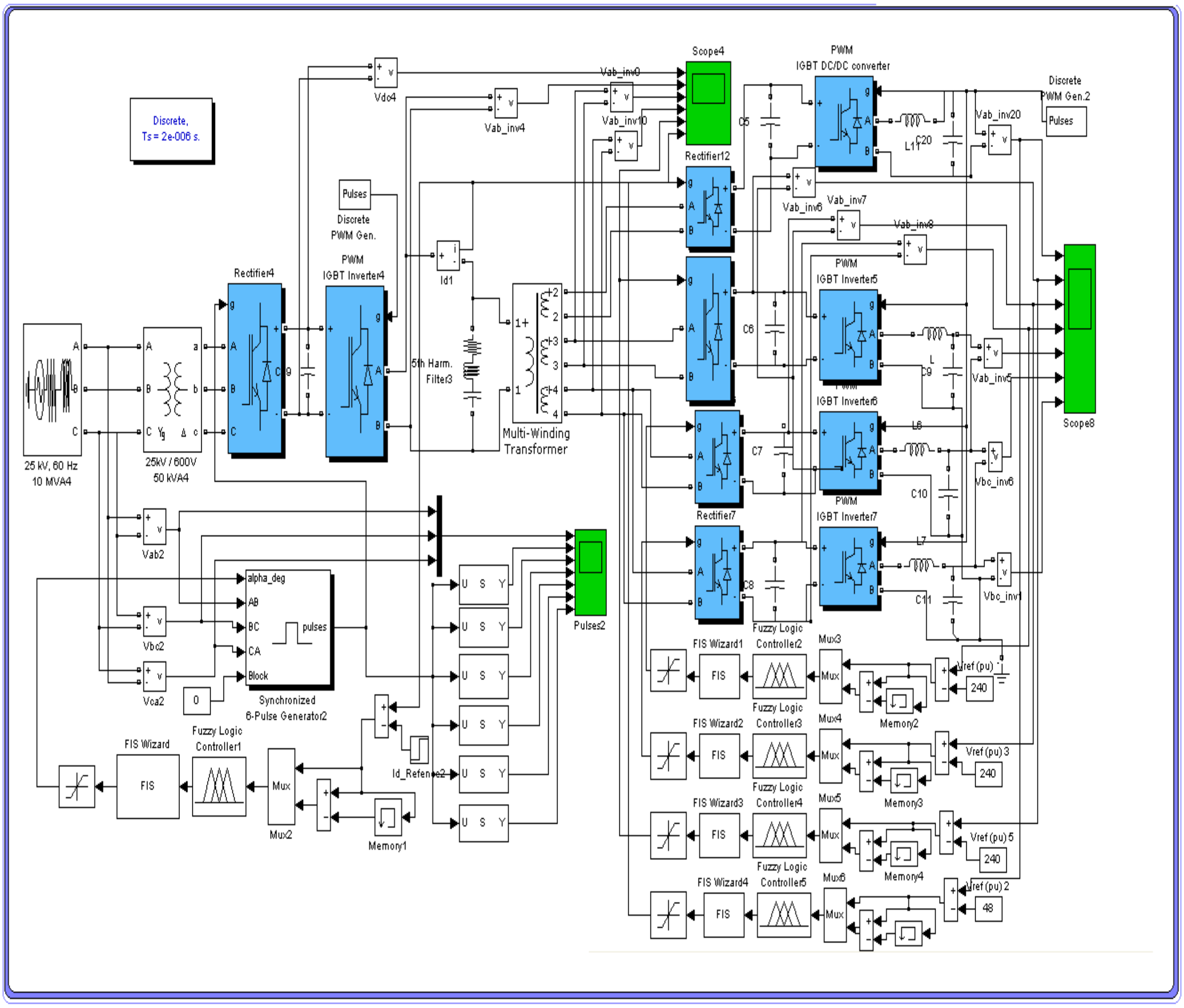

Fig. 10 IUT four layers topology including rectifiers, transformer, converter and inverters, four Fuzzy Logic Controllers for four outputs (48V DC, two 240V AC, 120V AC) and FLC for input current control

240V 60 HZ are the other two outputs converted from two 240V DC buses by DC/AC inverters. At this stage, two FLCs take the role of control for controlling the output voltages.Control surface (error, change of error and delta) is illustrated on fig 12.

49 FLC rules (seven states of error*seven states of change of error) are given in fig 13.

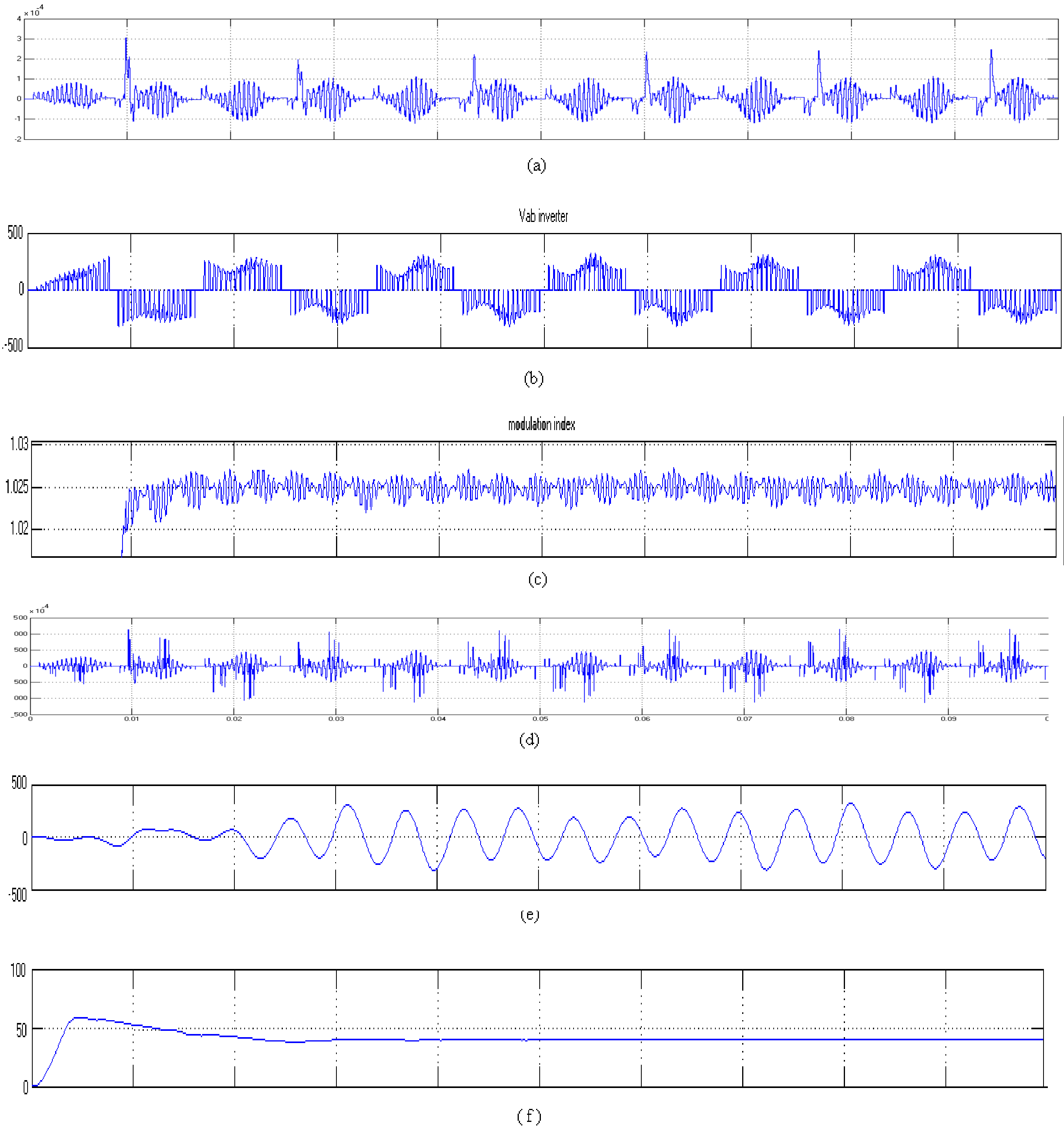

Fig. 11 Simulation Results : (a) error in FLC for 48V DC output, (b) change of error in FLC for 48V DC output, (c) modulation Index, (d) IGBT inverter output in DC/DC converter in output stage, (e) 240V AC output, (f) 48V DC output

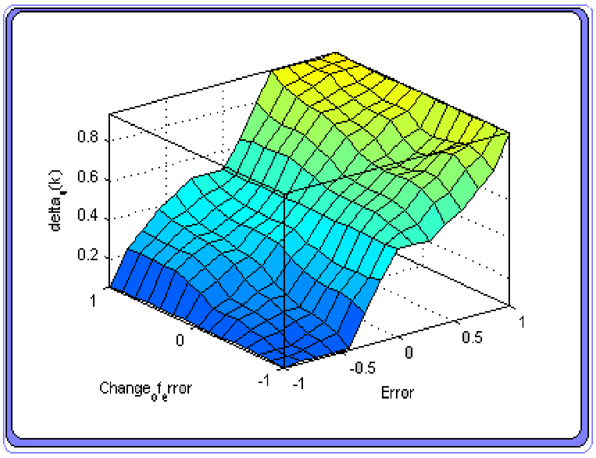

Fig. 12 Fuzzy logic control surface

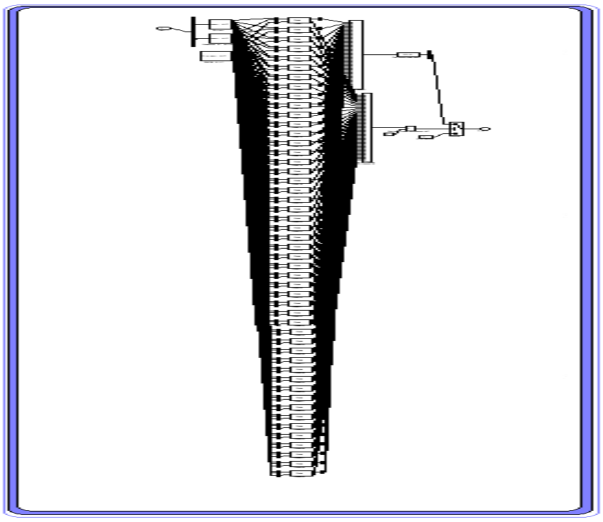

Fig. 13 49 fuzzy logic rules

I. CONCLUSION

FLC control methodology is concerned for overcoming on ambiguous conditions, nonlinear and complex system, enhancing the robustness for the new modern technology described as IUT.

IUT numerous benefits have been summarized in section 3. DC and three phase output voltages are the benefits arises by using four layers IUT topology. In this simulation four FLC controllers take the role of control and guarantee the stability and keep out the whole system from disturbances in input output stages. It also leads to efficiency enhancement in system performances.

ADA infrastructure has been raised in terms of future necessity will comprise the next distribution automation. It is directed towards full network functionality. Reliability enhancement is a part of innovation could be stated using modern adaptive solution for forthcoming projects especially for IUT in smart grid of future.

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ITRC "Iranian Telecommunication Research Center"1997-1998, "Synchronous Digital Hierarchy project, she was in charge of designing the management hardware and software which based on micro controller hardware connecting to the PC and connecting to 3 TU "tributary unit "and Com board through dual port RAM and a monitoring program which could show the Alarms of SDH in 2 Mega hertz ,1998-2000. she design TUT3 to TUG3 send and receive by FPGA Max plus 2 ,1996-1998.

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