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Robust Adaptive Fuzzy logic controllers for Intelligent Universal Transformers in ADA

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Abstract. Intelligent Universal Transformer (IUT) will comprise in Advanced Distribution Automation (ADA) with a new invention in control and management in future. It evolves with a high speed traditional transformer in addition to power electronic base construction will eventuate to oil elimination, dimensional size and weight reduction. Adaptive Fuzzy Logic Control (AFLC) is an adaptive progressed method with the high system performance capability being raised even on the uncertainty conditions. It enhances system stability, improves flexibility and releases designers from precise mathematical model utilization. Expert designer Knowledge is a critical requirement for conventional fuzzy logic controller (FLC), in contrast the AFLC rules and parameters are generated by adaptive model and human knowledge will downright initialize the first parameters values. In this approach four layers IUT topology is considered for developing the end user service options as 48V DC, reliable power as 240V AC 400HZ and three phase power option. AFLC schemes are proposed for employing current and voltage controllers in input output stages. Real time voltage regulation, automatic sag correction, Harmonic Filtering, energy storage option and dynamic system monitoring are the resulting benefits of using IUT four layers topology. AFLC methodology, leading the system robustness in any cases of grid and load disturbances.

Introduction (IUT for ada in future)

IUT is the new generation of transformers described for Advanced Distribution Automation [21], [6] rather than the current customary transformers.

ADA is the state of art with the Infrastructure technology based on open communication architecture, flexible electrical network and information exchange model [3], [7], [8].

ADA is a new invention for Distribution Automation [17] in future. It will provide a platform for delivering the traditional power with new services evolving the exchange of data and information in a dynamic style.

ADA will provide the estimation state in real time operations leads to fast prediction and enhances the performance of system including the electrical energy and efficiency. It also will improve reliability, quality and optimizes the demand by integrating the consumer facilities. Full automation in regard of all controllable equipment and ability for advanced reconfiguration is the other advantages of ADA. ADA employs the intelligent equipment devices (IED), Distributed Energy Resources (DER) and IUT.

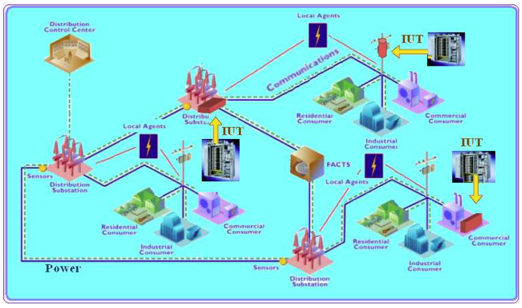

Fig. 1 IUT and ADA in the fortcoming smart power system

IUT basic concept and four layers topology is described in the next section. Section III, will comprise the Adaptive Fuzzy Logic concept and control strategy [1], [10]. Section IV elucidates the Matlab simulation results using AFLC in four layers IUT topology consideration. The last section evolving the conclusion of proposed AFLC with IUT topology.

IUT basic concept and four layers topology

IUT Concept. A multi level Intelligent Universal Transformer (IUT) emerging a next-generation of distribution transformers base on power electronic construction for incoming distribution automation [20]. automatic sag voltage compensation, real-time voltage regulation, outage compensation, Flicker mitigation, capacitor switching protection, harmonic compensation in nonlinear loads conditions, DC output service, reliable diverse power as variable frequency like 400Hz option, storing power, dynamic system monitoring, output voltage compensation in case of the built-in energy storage, capability on delivering three-phase power from a single phase, oil elimination, size and weight reduction are the most advantages of IUT rather than current traditional transformers [16], [22]. IUT comprises from a solid state converters evolving rectifiers, converters, inverters, DC Bus capacitors and HV transformer [2], [19]. DC/AC inverter could be configured for 400HZ output services or other variable frequency set by user.

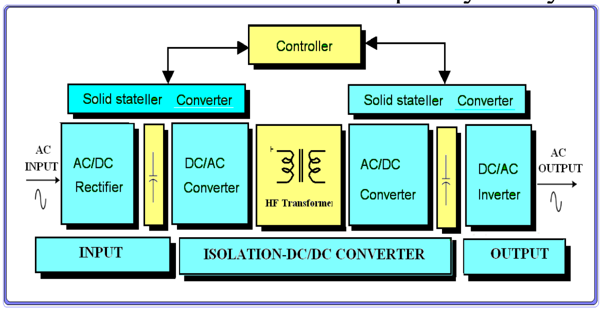

Fig. 3 IUT basic component diagram

High-frequency transformer couple the multi-level converters to a switched inverter circuit [4], [11-13], [18]. High-voltage distribution system will be coupled to the input section of the IUT using HV semiconductor equipment [14], [15]; low-voltage services are available on the output stage: 240/120 volts.

IUT Topology. Four layers IUT topology based on seven fundamental blocks is considered for this approach [5]. Multilevel rectifier (1r) and Inverter (1i) at the first stage for rectifying the input voltage and producing square wave, DC bus capacitors (2), HF transformer (3) for isolation inputs from outputs. Rectifiers and filters (4), make the DC output voltages. IUT divers outputs are (5, 6 and 7) including main inverter (5), assigning 120/240-V 60-Hz outputs, auxiliary inverter for 400 Hz option (6), 48-V DC output (7) from DC/DC converter.

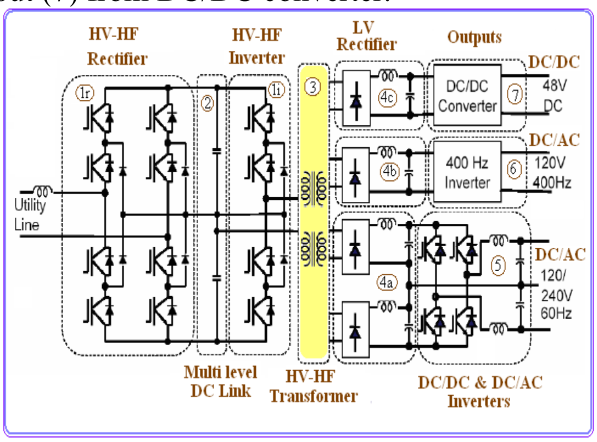

Fig. 3 IUT Topology

Adaptive Fuzzy Logic Concept and Control strategy

Parametric adaption is the heart of control strategy. In this regard, AFLC is a precise method in contrast with the other non adaptive control schemes. Fuzzy controller compensates the lack of information may exist in dynamic of system. It is a human knowledge defines as rules in sentences, producing the control strategy based on rule equations (fuzzy logic main notion) [9], [23].

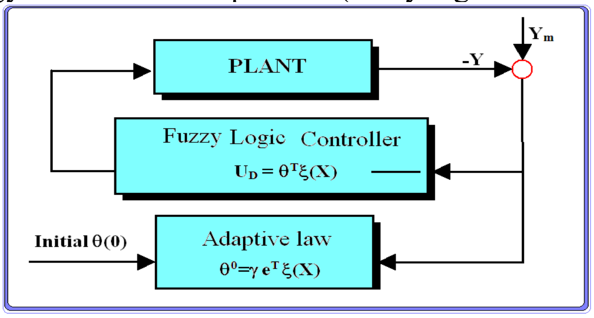

Fig. 4 Adaptive Fuzzy Logic Controller main topology

AFLC Concept. Adaptive fuzzy logic controllers are comprised from a fundamental fuzzy logic construction equipped with an adaption learning algorithm (Figure 5. Adaption low adjusts the parameters of FLC by training information so that the FLC rules automatically updated among training process. Human experiences assign the initial parameters in AFLC.

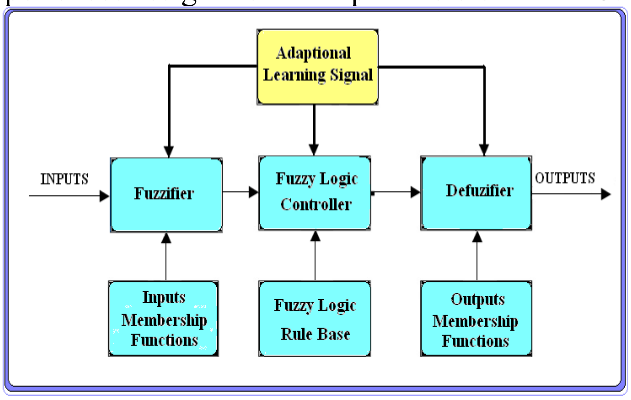

Fig. 5 Adaptive Fuzzy Logic concept

For a multi Input system with an output consider the inputs variable as x_j, $j = 1, 2, \ldots n$ and input parameters $i_1 = 1, 2, \ldots, N_1$, $i_2 = 1, 2, \ldots, N_2$, … $i_n = 1, 2, \ldots, N_n$, the inputs membership functions are A^j_{ij} and $C_{i1, i2, \ldots, in,}$ are the output membership function and $R_{i1, i2, \ldots, in}$ as fuzzy implication.

$R_{i_1 i_2 \ldots i_n}$: IF x_1 is $A^1_{i_1}$ and x_2 is $A^2_{i_2}$ …and x_n is $A^n_{i_n}$, Then y is $C_{j_1, j_2, \ldots, j_n}$, the fuzzy set will be in $U\times V$

$$U\times V = U_1\times U_2\times \ldots U_n\times V \tag{1}$$

Membership functions are:

$$R_{i_1 i_2 \ldots i_n}(x,y) = A^1_{i_1}(x_1) * A^2_{i_2}(x_2) * \ldots A^n_{i_n}(x_n) * C_{i_1 i_2 \ldots i_n}(y) \tag{2}$$

Where $*$ is T norm with $x = [\,x_1\ x_2\ \ldots\ x_n]^T \in U$ and $y \in V$

$$\xi_{i1,i2,\ldots\ldots in(x)} \subset \frac{\prod^{n}_{j=1} A^{j}_{ij}\left(X_j\right)}{\sum_{i1i2\ldots in\in I} \prod^{n}_{j=1} A^{j}_{ij}\left(X_j\right)} \tag{3}$$

$i_j = 1, 2, \ldots, N_j$, $j = 1, 2, \ldots, n$

$$U = \sum_{i_1 i_2 \ldots i_n \in I} \xi_{i_1, i_2, \ldots, i_n}(x)\, y_{i_1, i_2, \ldots, i_n} \tag{4}$$

the adjustable parameters are $y_{i_1, i_2, \ldots, i_n}$ defined as θ

$$U = \theta^T \xi(x) \quad (5)$$

The membership functions could be chosen as Gaussian form:

$$A^j_{i\,j}(x_j, P_{ij}, q_{ij}) = \exp - \frac{(x_j - p_{ij})^2}{2q^2_{ij}} \quad (6)$$

Control Strategy. Control strategy is based on controlling the input current in AC/DC converters and voltage regulation achievement predicated from outputs voltage controllers in DC/AC inverters. Whereof IUT is directly connected to the smart grid, so at primary stage, the input current have to maintain constant sinusoidal value and in phase with voltage for harmonic distortion cancelation.

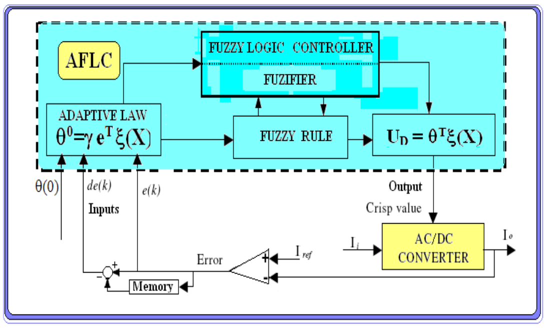

Fig. 6 Agaptive Fuzzy logic controller circuit diagram for Input current control (AC/DC converter)

AFLC takes the control duty in favor of robust control strategy.

Figure 7, depicts the voltage control scheme in output, AFLC keeps the outputs voltages stable in any load disturbances conditions.

The real time AFLC produces the control U in each cycle. The crisp value depends on the previous control value, parameter adjusting by adaptive, error and change of error.

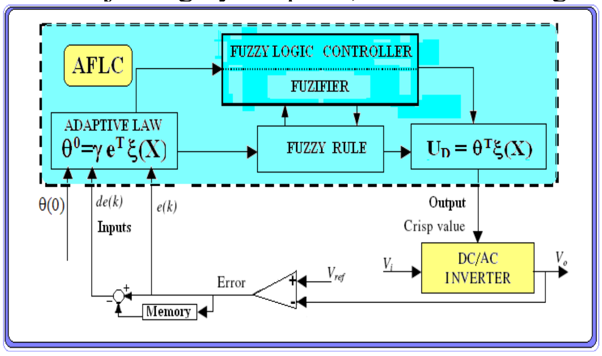

Fig. 7 Agaptive Fuzzy logic controller circuit diagram for output voltage control (DC/AC inverter)

In the case of great or few variations in input current or output loads in IUT the AFLC reflection will be entirely nonlinear according to the fact that the AFLC compensates the control strategy in conjunction to a nonlinear conversion.

Simulation in matlab

AFLC rules are illustrated in figure 8. Five states for error and five states for change of error have been considered so that, in overall 25 rules are extracted for fuzzy logic control.

Rules e	Δe NB	NS	ZR	PS	PB
NB	θ_1	θ_2	θ_3	θ_4	θ_5
NS	θ_6	θ_7	θ_8	θ_9	θ_{10}
ZR	θ_{11}	θ_{12}	θ_{13}	θ_{14}	θ_{15}
PS	θ_{16}	θ_{17}	θ_{18}	θ_{19}	θ_{20}
PB	θ_{21}	θ_{22}	θ_{23}	θ_{24}	θ_{25}

Initial Rules					
NB	NB	NB	NB	NB	NB
NS	NB	NB	NS	NS	NS
ZR	ZR	ZR	ZR	ZR	ZR
PS	ZR	PS	PS	PS	PB
PB	PB	PB	PB	PB	PB

Fig. 8 25 AFLC rules with initial values

Membership functions for error and change of error are indicated in figure 9, the Gaussian form on equation 6 is noted.

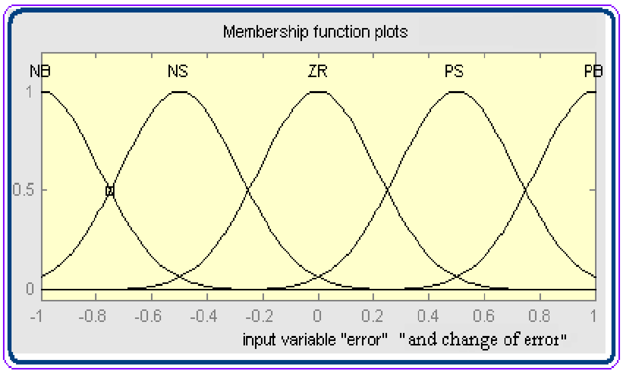

Fig. 9 Membership functions for error and change of error

IUT layout for four layers topology is depicted on figure 11. As it has shown, it is forming from PWM DC/DC converter delivering 48V DC, inverters with 120V AC and two 240VAC with 60 and 400 HZ outage with rectifiers and converter in input stage together with HV transformer.

Input current and output voltages are controlled by adaptive fuzzy logic scheme. The inputs of AFLC are error, change of error and initial value of parameter θ.

IUT is connected to the grid directly. It has shown here as 500V, three phase sinusoidal voltage (figure 11).

In the first stage rectifiers and converters rectify the three phase sinusoidal input and convert it to DC buss voltage. AFLC current controller fixed the input current, makes it in phase with input voltage and write-off the harmonic distortion (figure 10).

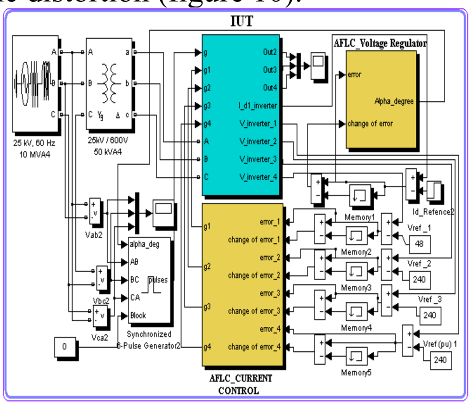

Fig. 10 FLC for current control and AFLC for output voltage regulation

Voltages in outputs have been regulated through the AFLC voltage regulator.
400HZ output voltage is developed for communication beneficiary.

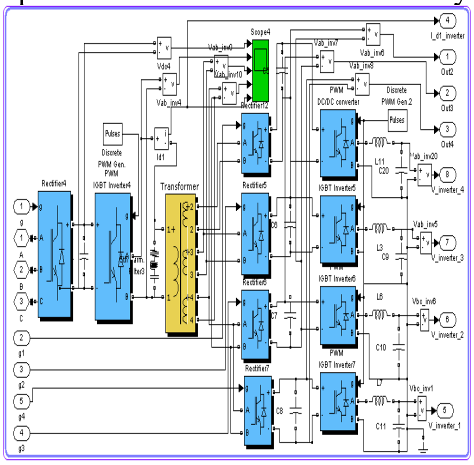

Fig. 11 IUT four layers topology in Matlab Simulation

In figure 12, error and change of error in AFLC voltage regulator, 48V DC and 240V AC 400 HZ outputs of IUT are represented.

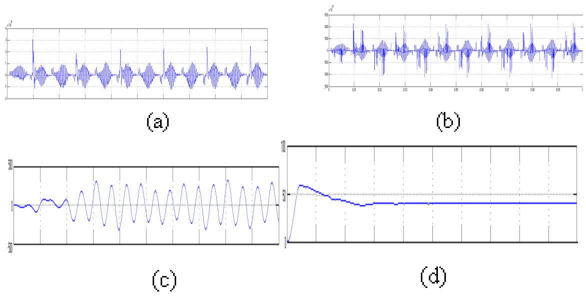

Fig. 12 (a) Error, (b) change of error, (c, d) Ac and DC outputs

Conclusions

Future distribution automation will be based on neoteric modern technologies comprise the flexible electrical architecture together with the open communication construction leads to full network functionality. It is the tremendous need on substituting the intelligent high speed electrical equipment in lieu of traditional distribution devices. IUT is described as a key electrical point for the Advanced Distribution Automation. IUT four layers topology with the benefit advantages is proposed for the simulation. AFLC current controller is introduced for harmonic cancellation and output voltage is regulated by AFLC in output stage. Adaptive control methodology provides the robustness leading in case of grid and load disturbances. AFLC tremendously improves the system performance and effectively adjust the control parameters by prior human knowledge extricates the designer from the precise mathematical model and expert knowledge.

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