Advanced Control Methodology for Intelligent Universal Transformers based on Fuzzy Logic Controllers

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Abstract: Intelligent Universal Transformer (IUT) is a power electronic base transformer introducing for Advanced Distribution Automation (ADA) in future. ADA is the state of art employing the new architecture based on both the flexible electrical network and open communication construction comprise the Future Distribution System. Fuzzy control is a method based on fuzzy logic concept emphasizes on fuzzy algorithms formulated by linguistically rules. Model free system, nonlinearity, robustness and flexibility under parameter variations are the benefit advantages of using fuzzy logic controllers. In this approach four layers IUT topology with the 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, DC voltage option, automatic sag correction, reliable diverse power as 400Hz service, 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 of using IUT four layers topology and fuzzy logic controllers.

Key-Words: ADA, IUT, IED, power electronic, FLC, membership function

1 Introduction

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].

IUT [7], [11-13], [18] 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 consider it as an Intelligent Electronic Devices (IED).
ADA overview is described in the next section. Section 3 will comprise the IUT basic concept and four layers topology. Fuzzy logic concept and control strategy are introduced in the next sections. Section 6 elucidates the simulation of FLC on four layers IUT topology. The last section evolving the conclusion and the prospective features of proposed FLC methodology.

2 Advanced Distribution Automation
The new methodology in control and management leads a gigantic revolution in distribution automation systems described as ADA. A flexible distribution automation evolving the full automated monitoring and control enrolling the new approach for exchanging the electrical energy, data and information in a dynamic manner among the consumers and system equipments. These occurred the purpose of developed electrical construction and open communication architecture in ADA topology.

3 Intelligent Universal Transformer
The new modern power electronic technologies supported creation of the new advanced technology described here as Intelligent Universal transformer (IUT).

3.1 IUT Concept
IUT is a high voltage low current power electronic base transformer in spite of traditional distribution transformers comprising the numerous advantages as new service option like automatic sag correction, DC voltage service, reliable diverse power as 400Hz service, 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.

3.2 IUT 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 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).

4 Fuzzy Logic Concept
Fuzzy logic controllers are the powerful control method has been proposed first by Lofty Zadeh. 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].
5 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. So in the input stage, FLC in AC/DC converters senses the input current in IUT and enrolls the duty of control for preventing any disturbances from the grid.

![Fig. 5 Fuzzy logic controller for AC/DC converter in Input stage (Current source controller)](image)

In the output stage the FLC take the role of keeping the output voltage constant in the condition of load disturbances figure 6.

![Fig. 6 Fuzzy logic controller for DC/AC inverter for controlling the AC outputs (voltage source controller)](image)

Membership functions for error and change of error are illustrated in figure 7.

![Fig. 7 Membership functions for error, change of error and duty cycle change of output](image)

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. 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 8.

![Fig. 8 Fuzzy control Rule Bade](image)

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

\[
    w_i = \min\{ \mu_e(e), \mu_{ce}(ce) \} \quad (1)
\]

The inferred output \( u_i \) being achieved by

\[
    u_i = w_i \cdot y_i. \quad (2)
\]

\( y_i \) 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:

\[
    \Delta d(k) = \frac{\sum_{i=1}^{n} u_i}{\sum_{i=1}^{n} w_i} \quad (3)
\]

\[
    d(k) = d(k-1) + \Delta d(k) \quad (4)
\]

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.
6 Simulation In Matlab

Fig 9 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 HF transformer, four Voltages hold constant by four FLC’s in output stage. PWM DC/DC converter makes 48V DC from the first DC buss.

The FLC measures the output voltage, compares it to desired 48V DC and makes it constant (voltage source control). 240V 60 HZ are the other two outputs converted from two 240V DC buses by DC/AC inverters. Two FLC’s take the role of control voltage at this stage. 120V AC 400 HZ is the last DC bus develope for communication usage. Simulation results are shown in fig 10. Control surface, 49 FLC rules are given in fig 11.
6 Conclusion

FLC control methodology is concerned for overcoming on ambiguous conditions and reaching robustness for the new modern technology described as IUT in this article. 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 lead 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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