**DC Microgrid and Control System**
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**Lecture - 22**
**Intelligent Microgrid Operation and Control**

Welcome to our discussion on the DC Microgrid and the Control System. Today, we will talk about the intelligent control in the microgrid applications.

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So, our presentation layout will be the upgrade production that is intelligent control technologies. We shall talk about detail with fuzzy logic control, then fuzzy logic system as main controller which we have discussed in previous class, fuzzy logic control for tuning, and fuzzy logic controller as a supplementary controller. So, we shall see all those aspects how fuzzy logic FLC is used.

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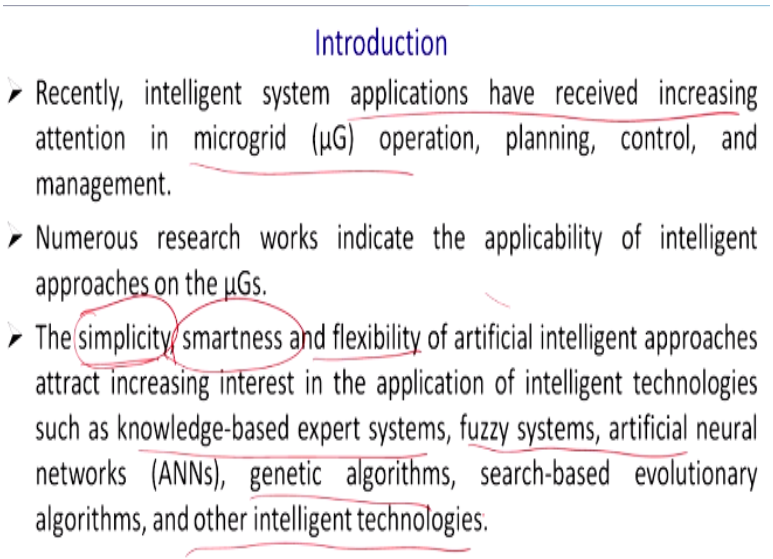


So, recently, the intelligent control system application has received increasing attentions because ultimately when you have a conventional PI controller and other issues, challenges is mainly to tune the PI controller and it works when you know the transfer function very well, and in most of the cases, it is difficult to derive the transfer function and since the system is nonlinear, so it doesn't function very well.

So, you have to take a help of the nonlinear controller, and instead of a nonlinear controller, many researchers are now putting their observation as a research on the FLC and thus it has become an emerging field in FLC or ANN based or any other intelligent controller will be applied for the microgrid operation. In microgrid operation, so intelligent control can be applied planning control as well as the management.

So that is what I was telling that numerous research work indicates that applicability of the intelligent approaches in microgrids, so there are many research papers on this intelligent control, and why it is so, it is because simplicity because if you understand because our world is fuzzy, our world is not script set, it is human who actually talk about the cript set, like for example, I am a faculty of IIT Roorkee and if someone is not faculty of IIT Roorkee doesn't belong to our set, but it is not like practical cases, like when you say that today is warm or cold, it is not like that scrip set.

Since it walks in our human linguistic ages, so it has got a huge advantage to use it when you have a, it is it has got attenuations or understanding with the human languages. That is one of the biggest aspects and helpful while actually describing the fuzzy set, and for this reason, it is simple. So, while setting a task of FLC, general layman will find more comfortable. Of course, mathematicians may have opinion on the script set of the fuzzy set that what about the stability study and all, but it is simple, smart, if you design very intelligently, it will become a smart. It has a flexibility.

So, flexibility also it can take its own decision and thus it can have a different kind of flexibility can be incorporated here of the artificial intelligent control approach. So, it is a failed self-correcting act that increase the interest in applications of the intelligent technologies such as knowledge-based expert system, you have a trend data sets or you know that input and output and then you try to interpolate this data in between, that is called knowledge-based system, fuzzy system, fuzzy and ANN almost a same kind of system, so fuzzy and their artificial neural networks.

Then you may have a heuristics system of optimizations. These are different search algorithms, these are genetic algorithm and search-based particle sum optimizations and colony name you know better than me perhaps, search-based evolutionary algorithm, and other intelligent technologies that can find its applications in microgrid and huge amount of paper you will find has been devoted on it.

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## Introduction (cont...)

- The μG stability and control synthesis/analysis have been augmented with valuable research contributions in the past decade.
- Significant improvements have appeared in the area of control synthesis to cope with uncertainties, various load characteristics, changing structure, and integration of high rate of renewable energy sources (RESs) and energy storage systems (ESSs).

So, the microgrid stability and the control and synthesis have been acquainted with the valuable research contributions in the past decade. So, it has been the contribution because it is decade of the intelligent control and thus, this micro application of the microgrid finds lot of applications in intelligent control. Significant improvement have been appeared in the area of the control synthesis to cope with the uncertainties, various load characteristics, changing structures, integration of the high rate of renewable energy sources, and energy storage limit.

So, these are few aspects that force us to use the intelligent control.

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## Intelligent Control Technologies

- In recent years, some of the advent of modern intelligent methods arisen are:
  - Artificial neural networks (ANNs)
  - Fuzzy logic
  - Multiagent system (MASs)
  - Genetic algorithms (Gas)
  - Particle swarm optimization (PSO), and
  - Hybrid intelligent techniques

And in recent years, some of the advent ment of the modern intelligent control methods are definitely the ANN, so it is evolving from 70s, professor Zadeh is an Iranian professor. He came out first with fuzzy sets and so that is something it is been extensive used in microgrid applications, FLC controller, multiagent system that is MAS, so that is also used for a multi-optimization technique. Thereafter, you may have a particle swarm optimization technique that is PSO, and another optimization technique is aspired from our evolutions.

It has been considered that our kids are much smarter than us, it is because of the evolutions, and that entity has been taken into consideration while designing the controller and it walks on the optimization technique and the heuristic optimization technique and, but convert it this to has a convergence problem and for this reason, hybrid intelligence technique is used, where you have a normal gradient-based optimization technique, then you coupled with this genetic and particle swarm and other optimization techniques to get better results. So, that is the hybrid intelligent techniques.

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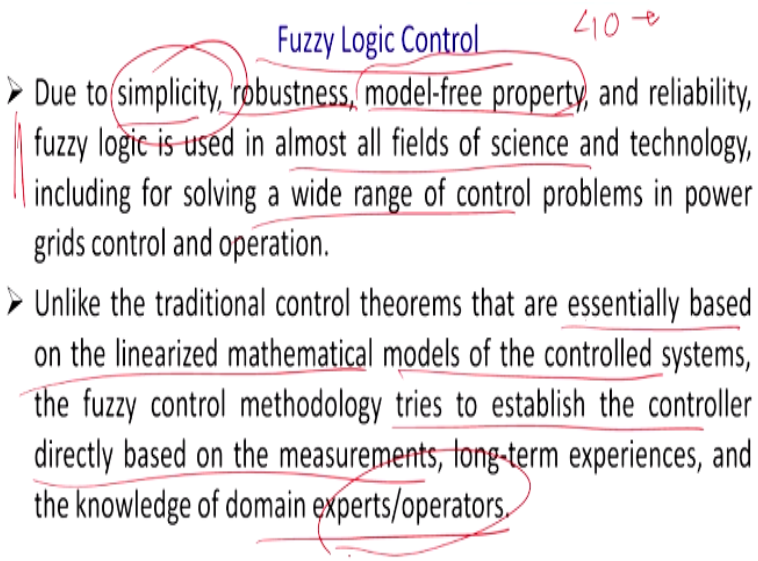


Now, let us first discuss about the fuzzy logic controller, we abbreviate as FLC sometimes. Due to the simplicity, why simple because he works on the linguistic ages and that is that human beings are familiar with. The robustness and you give a number to your membership functions. Say you say actually in your cities if the 40 degrees centigrade, you say it is the hottest; if it is

30, you say warm So, accordingly in case of the hot, what should be the membership function, you can linearly define something and for this reason, it is simple.

It is robust because it has its own fault tolerant capability and model-free property, that is one of the biggest problem, we require to make a model and ultimately while designing their prototype. So, if you know this when you are scaling down or scaling up, you require to know the knowledge of the mathematical model. So, that mathematical model knowledge is not required in case of the fuzzy logic.

So, you can scale it down and scale it up so without having the knowledge of the model, and reliability has been proven that it is quite reliable, and for this reason, fuzzy logic is used in most of the field of the science and technologies including solving a wide range of the control problem in power grids and operations. So, it works that is the advantage of it, from the field engineers are saying these are the words simplicity, robustness, and reliable.

So, what is the difference with the traditional control stories, unlike traditional control theorem, there are essentially they are essentially based on the linearized mathematical model because world is nonlinear. Once you apply the linear control system, that is the knowledge based the human being is having, ultimately it zeroes down everything to the se second order system, second or a linear system and talk in terms of the board (( )) (10:59) sport and blah blah blah and thus what happened, try to approximate neighborhood of this of this nonlinear system, but it has lot of problems.

So, it will act only close to its neighborhood, not pretty far behind. So, models of the control systems are to be mathematically driven and it is merely in approximations. And on the other hand, the fuzzy logic methodology tries to establish the controller directly based on the measurements, long-term experiences and the knowledge domain of the experts or the operators. So, when you know the cause and effect relation, that is basically the fuzzy expert system. You know if it is warm, you required to this cloth.

Say if it is a fuzzy logic controlled washing machine, you know that if the cloth is dirty and that cloth is jeans, so this will be the time it has to be set for your washing machine, that is a rule base.

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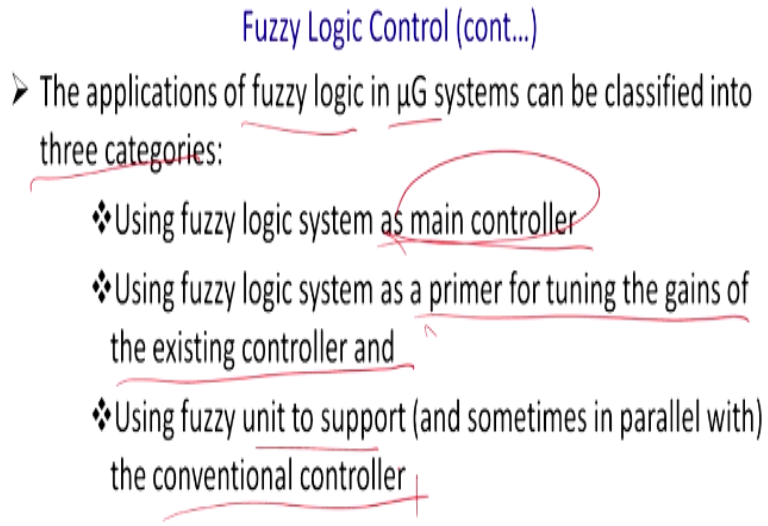


The application of the fuzzy logic in microgrid system can be classified into the 3 categories. Using fuzzy logic system as a main controller, you have seen that is mostly in a master-slave controller that can be a main controller; using fuzzy logic system as premier for tuning gains of the existing controller, you may have a different, as you have seen that you have a different controller, in peer-to-peer network, you required to have PQ controller and we have discussed so many PI controller.

Ultimately, this PI controller will act well if you have optimally designed the value of the kp and k. And for this reason, getting their closest approximation of the best approximations of the PI controllers, we can use the help of the fuzzy logic without having the knowledge of the plant. So in that area also fuzzy logic can work. So, that is what it says using fuzzy logic system as a premiere for tuning the gains of the existing controller, and what else, using the fuzzy unit to support and sometime parallel with the conventional controller.

So you have to put it into the parallel, whomsoever gives the best results, you will take it and you may not discard because you have a conventional wisdom on the PI controller, you take the

juice from the PI controller. Once you see that actually you know it has overshoot is more because it ultimately boils down to the everything in the second order system, its shuttling time is more, its gain and you cannot do anything.

You find that ultimately tuning everything, you go a controller where whose gain machine fetch machine has a problem, and in that case, we put an extra controller parallel to it once you find that okay, it is not possible to beyond with the conventional controller, let us put a PI another FLC controller parallel to it. Ultimately, it will fine tune the process or it will take the steps based on the error.

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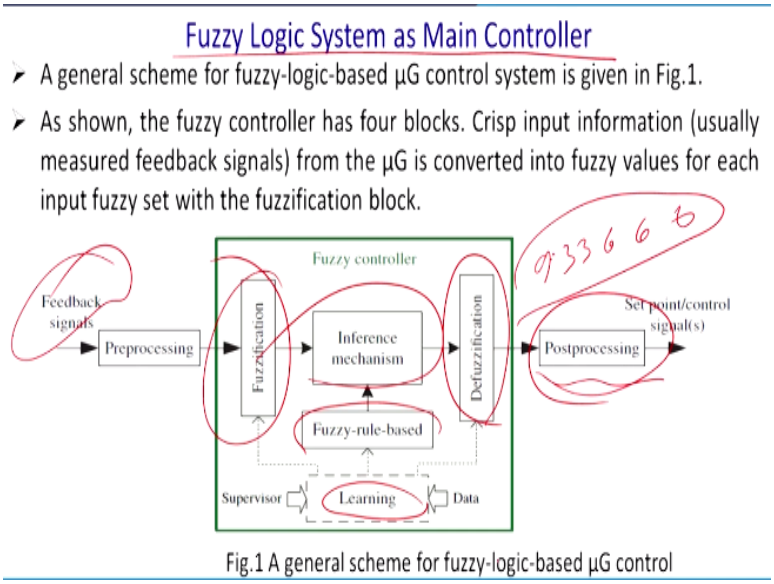

Fig.1 A general scheme for fuzzy-logic-based µG control

So, this is the fuzzy system as a main controller. This is a block diagram of it. You have the actual measure status. There is feedback signal, thereafter it will undergo some processes to eliminate noise and others, then you will have a fuzzification based on the rule base. You have TS fuzzy or Mamdani fuzzy depending on a different kind of or where you will required to have a linear or the nonlinear classifications.

Thereafter, you have a interfaced mechanism and you will take, this is basically the supervisor and this is the data and thus you got a rule base and this rule base was formed from fuzzification or interface mechanism and this is a fuzzy rule based, then you will have to defuzzify and ultimately there are different method, of course centroid method or other

methods. It will calculate the area, ultimately it will take out the time. So, ultimately it has to find it out what should be the one single input, the value of kp, you have so many inputs.

So, what should we the value of kp and ki. In case of the washing machine, what will be the timing. So, that is a defuzzificaitons. There are many methods of defuzzifications and thereafter postprocessing because you know if it generates some value, because if it generates 9.3333666 as a value of the PI controller, and of course, you cannot provide that value, and for this reason, you have to give some kind of approximation, that is the postprocessing of the signal and that value you feed it to the plant.

So, this is a way you will work on the fuzzified system or the fuzzy logic as a main controller, we will continue with it.

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Fuzzy Logic System as Main Controller (cont...)

- The universe of discourse of the input variables determines the required scaling/normalizing for correct per-unit operation.
- The inference mechanism determines how the fuzzy logic operations are performed and together with the knowledge base, determines the outputs of each fuzzy *if–then* rule.
- Those are combined and converted to crispy values with the defuzzification block. The output crisp value can be calculated by the center of gravity or the weighted average; then, the scaled output as control signal is applied to the generating units.

The universe of discourse is the mathematical term of the input variable determines, where the universe of discourse is like the theta and your function is sine. So, your output is a sine theta, it varies between -1 to +1, determines the required scaling normal and normalization, that is something we require to do that to correct per unit operation. So, that is this kind of normalization is required to split it to the model. The reference mechanism determines how the fuzzy logic operations are performed.

Together with the knowledge base determine the output of that each fuzzy if and then rule, it is a causal effect. If this, then this. Those are combined with combined and converted to the crisp value that is a normal method, normal set value, with the defuzzificaiton block. There are many ways to defuzzify it and the output of the crease value can be calculated by the centre of gravity or the weighted average and then the scaled output as a control signal is applied to the generating unit. This is a way any FLC will work, not only in case of the microgrid, but for any purpose.

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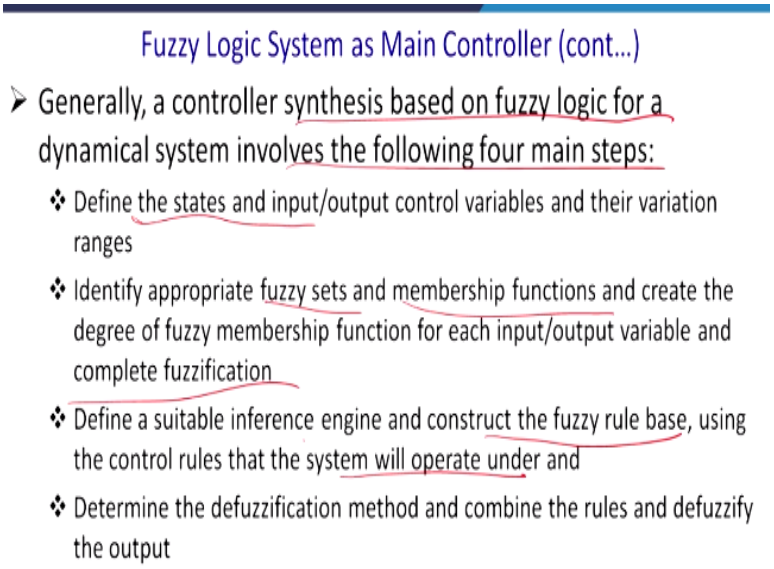


Generally, a controller synthesis best a fuzzy logic for dynamical system involves following four main steps, let us see one by one. Define the states and the input/output control variable. and their various range. Whenever you say the states in the control system, we always understand the current through the inductor and the voltage across the capacitor, but its scope is beyond. So, it can have a different state also, different quantity and state.

Identify appropriate fuzzy sets and membership functions and create degree of fuzzy members function for each input and output variable and complete fuzzification. So, we have to based on this thing, we have to complete the fuzzification. Thereafter define a suitable interference engine and construct the fuzzy rule base. So, that is that record an expert system, if and then logic, using the control rule that the system will operate and determine the defuzzificaiton

methods and combine the rule and defuzzify the output and put it to the plant for action. This is the way the FLC or all the fuzzy logic systems will work.

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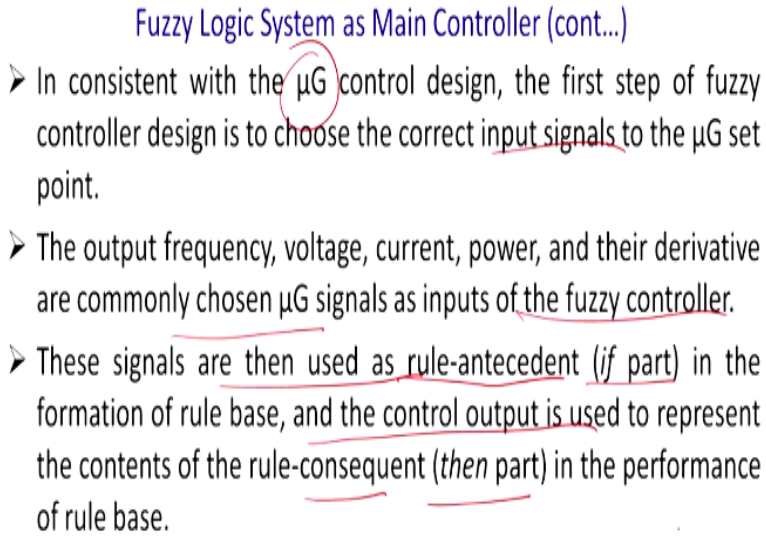


In consistent with the microgrid control, the first step of fuzzy, let us see that how it will it can we implement our microgrid. Control design is to choose the correct input signals to the microgrid set points, the voltage, current and other if it is a AC microgrid, then frequency, then PQ values, whatever may be the value require, you will take it from the set points. The output frequency, voltage, current, power and their derivative are commonly chosen as microgrid as an input of the fuzzy controller.

Thereafter what has it been done? The signals are then used as rule-antecedent, that is the if part, so this is the if. So, this is now voltage is this, current is this, power is this, frequency is this, this is the if part, load is this in the formation of the rule base and the control output is used to represent the content of the rule consequent, that mean it is called the then part, in the performance of the rule base.

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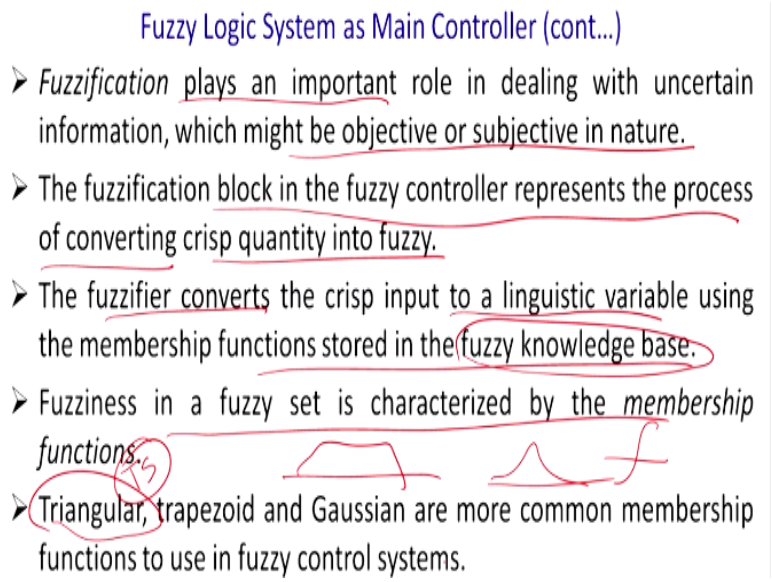


Fuzzification plays an important role in dealing with the uncertain informations, which might be objective or the subjective in nature. Sometimes, we may have a mathematical score relations, so that is objective and sometimes we may not have a mathematical correlations, that the subjective. The fuzzification block in the fuzzy controller represents the process of converting this crisp quantity into the fuzzy.

So, you will say that the membership by the membership function, you say that till 40, it is young, then if someone is 35, is it a membership function, till 40 it is young, so within the membership function, he may have a value of 0.2, at 40 that value is 0. So, it is something like this. The fuzzifier converts the crisp input to the linguistics variable using the membership functions stored into the fuzzy knowledge base, that has to be formed with due precisions as well as the informations.

This rule base is a key of the FLC, you have to design the rule base with an expert system. Fuzziness is the fuzzy set characterized by the membership functions. There are different kind of function you can choose, triangular, well mostly in a TS fuzzy we choose triangular; it can be trapezoidal; it can be Gaussian are the or it can be this kind of thing sigmoid and so many are there and are common membership functions used in the fuzzy logic control.

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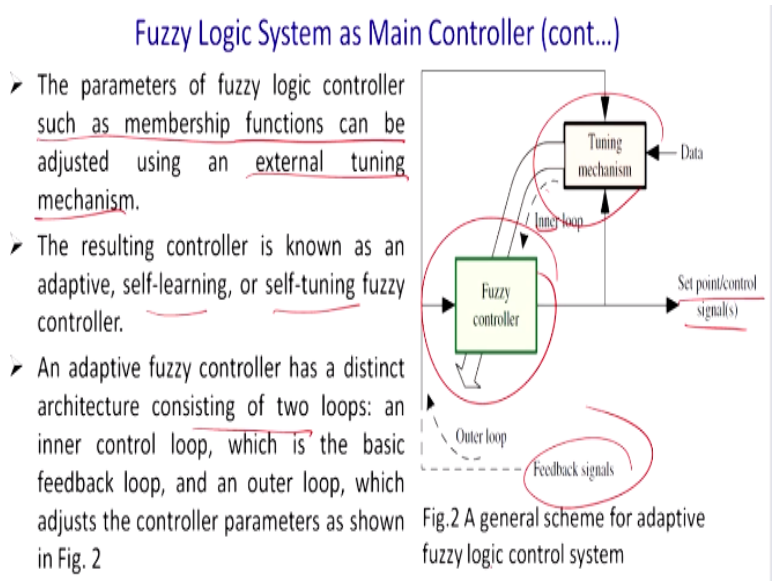


The parameter of fuzzy logic controller such as membership functions can be adjusted using an external tuning mechanism. So, you have to be tuned properly and that is the usage of this. So, you have a fuzzy logic controller, you have a tuning mechanism, you got a data, so that is the inner loop, and you got a different set point, this is outer loop that is a feedback signals. The resulting controller is known as an adaptive, self-learning or the self-tuning fuzzy logic controller, if it can.

So, you got a training mechanism and that will change the controller's parameters. Adaptive fuzzy logic controller has a distinct architecture consisting of 2 loops, an inner loop, this one is an inner loop, and outer loop which adjusts the controller parameter as shown in the figure 2.

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## Fuzzy Logic System as Main Controller (cont...)

- The adaptive fuzzy controllers commonly use some other intelligent techniques such as neural networks in the tuning block, which have learning capability.
- This combination provides *neuro-fuzzy* controller. A neuro-fuzzy controller is a fuzzy controller that uses a *learning algorithm* inspired by *neural network* theory to determine its *parameters* by processing data samples.

The adaptive fuzzy logic controllers commonly use some other intelligent technique, it may be ANN such as neural network, in tuning block, which have learning capability because you know if and then, then you can change the way it is and it will learn and these combinations provides the and it is said to be the neuro-fuzzy control. The neuro-fuzzy controller is a fuzzy controller that uses the learning algorithm inspired by the neural network, backpropagation algorithm, or any other algorithm, LMQ algorithm and determines the parameter by processing the data samples.

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## Fuzzy Logic for Controller Tuning

- The PI control structure has been widely used in the power grids as well as at μG control levels due to its structure simplicity and inexpensive cost.
- The success of the PI controller depends on the appropriate choice of its gains.
- Assume the feedback signal to feed the PI controller to be $e(t)$, then the control signal generated by a PI controller in the continuous-time domain is represented by

$$u(t) = k_p(t)e(t) + k_I \int_0^t e(\tau)d\tau \qquad (1)$$

Now, let us take an example of fuzzy logic for the controller tuning. Let us take a simple example the PI controller. The PI controller structure has been widely used I n the power grids

as well as the microgrid controller level due to its structural simplicity and inexpensive in costs and now you can because it can be implemented because integrator can be an analogue domain, integrator can be put into the operation by an op-amp. So, and the gain also can be put into the operation by an op-amp.

So, operation amplifier, one operation amplified is sufficient to be used as a PI controller. So, for this reason, it is quite inexpensive. Nowadays in the digital domain, you can have a digital play controls also, that can be implemented by the various processes. The success of the PI controller depends on the appropriate choice of its gain, the value of the kp and ki. Assume the feedback signals to feed the PI controller to be et that is the error signal we sometimes say, then the control signal is generated by the PI controller in the continuous time domain is given by ut = kp x et + ki 0-t integration of e tau pub d tau.

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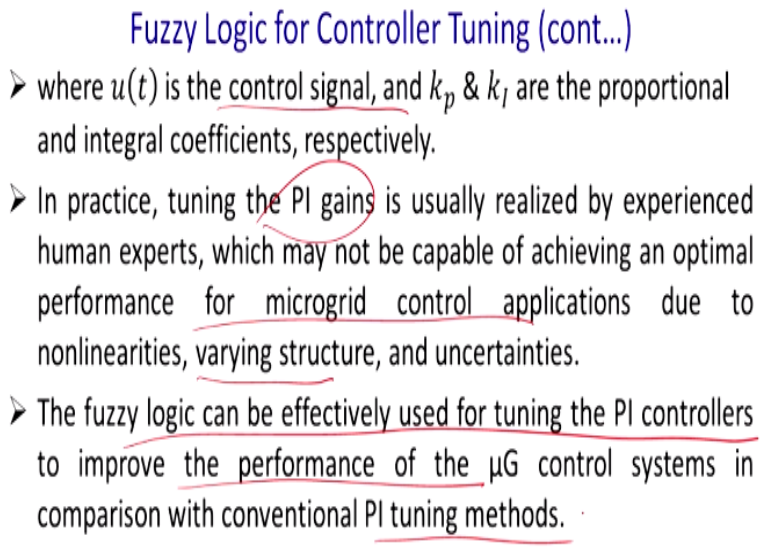


Where ut is the control signal and kp and ki are the proportional and integral controller of this PI controller respectively. In practice, the ti the PI gains are usually realized by experienced human experts. So, you have to, someone has to stay, but there are different methods, Nichols-Colin methods to tune the PI controller, but you require to know the plant model them, which may not be capable of achieving by an optimal performance of the microgrid controlled applications due to the nonlinearities, varying structures, and uncertainties of the loads and the source and this comes from both.

Here, fuzzy logic can play an important contribution. Fuzzy logic can be effectively used to tune the PI controller to improve the performance of the microgrid control system in comparison with the conventional tuning methods.

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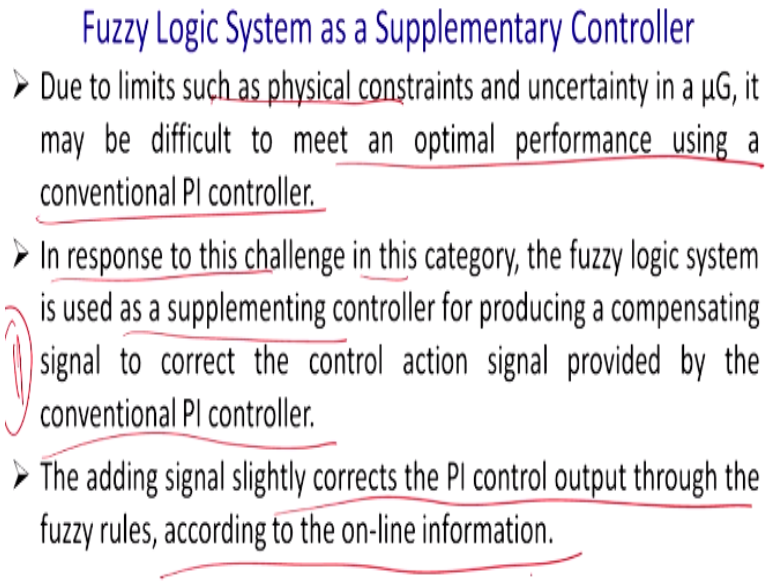


Due to limits such as physical constraint and uncertainty in the microgrid, it may be difficult to meet an operational performance using a conventional PI controller. So, that is quite challenging, you require to have a mathematical model. The response to this challenge in this category, the fuzzy logic system is used as a supplementing controller to provide a compensating signal to the correct control action signal provided by the conventional PI controller.

So that is the advantage of FLC. So, by adding the signal slightly corrects the PI controller output through the fuzzy rule according to the on-line information is the task of the FLC that will fine tune the PI controller processes.

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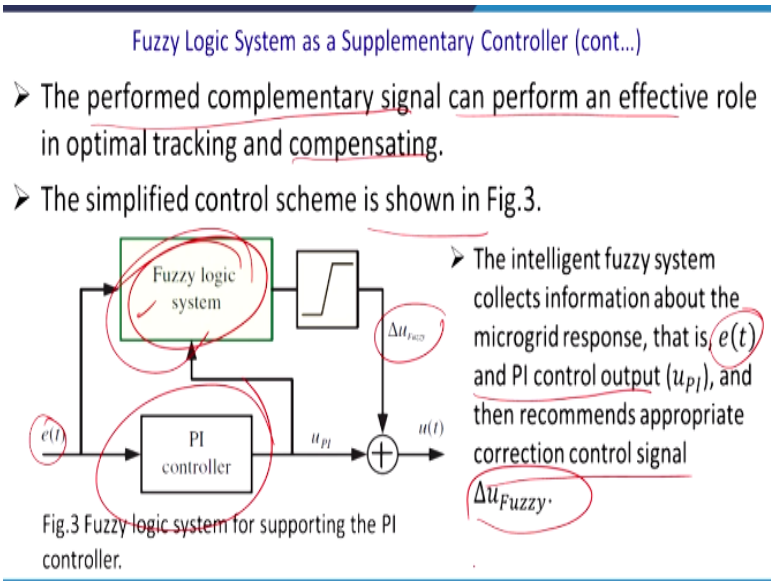


So, what happened, this is a plan model. You got a PI controller, you got a fuzzy logic system and PI controller, this is the input to the PI controller, this is the FLC, you have a limiters and ultimately you get the value ut, you supposed to get from the PI controller, but it will fine tune the process of the PI controller, it may be sum, it may be subtracted, the way you are using the different of it.

The performance compensated, the performed complementary signals can perform an effective role in optimally tracking and decomposing, whereas, you may have something if you have a large error, then output can be very high, and when you have a least error, but value of the kp may be required to be reduced, but you cannot do that. So, for this reason, this fuzzy logic system can act very fast and this is an oversimplified rather control scheme as it is shown in the figure 3.

The intelligent fuzzy system collects the information about the microgrid response, that is et, it can be voltage, current, frequency for the AC microgrid or the DC voltages for the DC microgrid and PI controller output and then recommends appropriate corrections of the control signals that is the del u fuzzy.

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Fuzzy Logic System as a Supplementary Controller (cont...)

- The fuzzy system performs as an automatic tuner. The main components of this system as an intelligent fine-tuner for the conventional PI controller include:
  - A feedback (through the $e(t)$ signal),
  - Extract knowledge about the performance of the existing PI controller (through the $u_{PI}$ signal), and
  - An embedded unit to suggest suitable correction ($\Delta u_{Fuzzy}$) to be made to the final control action signal ($u$) as follows:

$$u = u_{PI} + \Delta u_{Fuzzy} \qquad (2)$$

So, the fuzzy system performs as an automatic tuner. The main component of the systems is an intelligent fine-tuner for the conventional PI controller and it includes the following entities; that is feedback through the et signal, extract knowledge about the performance existing PI controller through the upi signals, and embedded unit suggests the suitable corrections of the u fuzzy to be made with the final control action u and thus this is your action u = upi + del u fuzzy, that will ensure that more proper action of the PI controller.

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Fuzzy Logic System as a Supplementary Controller (cont...)

- And

$$u_{PI} = k_p(t)e(t) + k_I \int e(t)dt, \Delta u_{Fuzzy} = f(e, u_{PI}) \qquad (3)$$

- where $k_p$ and $k_I$ are the proportional and integral constant gains of the PI controller, respectively.
- The $f(.)$ denotes the fuzzy logic function.

If you add up these things, what you can see that it actually have a, so this is the upi, this is kp+ki, thereafter it has a PI controller, then you got a new fuzzy and this now this PI controller is a function of the error as well as the u fuzzy, where kp and ki are the proportional integrated

controllers, gains of the PI controller respectively, and the f dot, now it denotes the fuzzy logic function, it can be sigmoid, it can be anything else.

Thank you for your attention. So, in this way, FLC can be used through the parallel to the PI controller to further process the PI controller. Thank you