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# An Adaptive Vague Controller based Power System Stabilizer

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**ABSTRACT:** This paper presents an adaptive Power System Stabilizer (PSS) using an Adaptive Network Based Vague Inference System (ANVIS). An Adaptive Vague Set Based Controller Power System Stabilizer (AVCPSS) has been evaluated. This AVCPSS is capable of providing appropriate stabilization signals over a broad range of operating conditions and disturbances. A Vague Controller (VC) is synthesized by using the notion of vague sets, which are a generalization of fuzzy sets and synonyms of the interval type fuzzy set. In the proposed vague expert system, speed deviation and its derivative have been selected as vague inputs.
**Keywords—** Adaptive Network Based Vague Inference System (ANVIS); Adaptive Vague Set Based Controller Power System Stabilizer (AVCPSS)

## I. Introduction

In an attempt to cover a wide range of operating conditions, expert or rule based controllers have been proposed. Recently, the vague set theory introduced by W.L.Gau and D.J. Buehrer[3] has been conceived as a new efficient tool to deal with ambiguous data and it has been applied successfully in different field. The vague set theory is a new concept extended form for fuzzy sets [1] and synonyms of the interval type fuzzy set [4]. It expresses for and against evidence .Vague logic makes complex and non-linear problems much easier to solve by allowing a more natural representation of the situations being dealt with.

Low frequency oscillations occur in power systems due to disturbances. If no adequate damping is available, such oscillations can increase and cause system separation. Power system stabilizers (PSS) are installed in power systems generators to enhance damping [7,8] and provide supplementary feedback stabilizing signals which extend the power stability limits.

As far as modern control theory is concerned, several approaches have been proposed to improve the PSS design problem; these include optimal control, adaptive control, variable structure control and intelligent control [2,5]. In [6] an adaptive fuzzy synchronous machine PSS that behaves like a PID controller for faster stabilization of the frequency error signal and less dependency on expert knowledge is proposed. The present paper introduces a power stabilizer based on vague set logic and ANVIS (adaptive network based vague inference system) design controllers. In this Vague logic based design, a rule was extracted from a conventional controller to give an initial solution. A speed deviation and its derivative are used as an input to the PSS controller.

The ANVIS combines the advantages of Vague set based Controllers (VCs) and Artificial Neural Network Controllers (ANNCs), avoiding their problems.

## II. Vague Set Based Controller (VC)

A vague set (or in short VS) A in a universe of discourse U is characterized by a truth membership function $t_A : U \rightarrow [0; 1]$ and a false membership function $f_A : U \rightarrow [0; 1]$, where $t_A(u)$ is a lower bound of the grade of membership of u derived from the 'evidence for u', and $f_A(u)$ is a lower bound on the negation of u derived from the 'evidence against u', and $t_A(u) + f_A(u) \leq 1$.The vague set A is bounded by a subinterval $[t_A(u), 1- f_A(u)]$ of closed interval [0,1]. This indicates that if the actual grade of membership is $\mu_A (u)$, then $t_A(u) \leq \mu_A (u) \leq 1- f_A(u)$.

When the universe of discourse U is continuous, a vague set, A may be written as

$$A = \int_U \ [t_A(u), 1- f_A(u)] / u \ , \ u \in U \qquad (1)$$

When the universe of discourse U is discrete, a vague set A may be written as

$$A = \sum_{i=1}^{n} \ [t_A(u), 1- f_A(u)] / u, \ , \ u \in U \qquad (2)$$

A vague set in the universe of discourse U is illustrated in Fig. 1. For the basic operations and properties on vague sets the readers can refer [3].
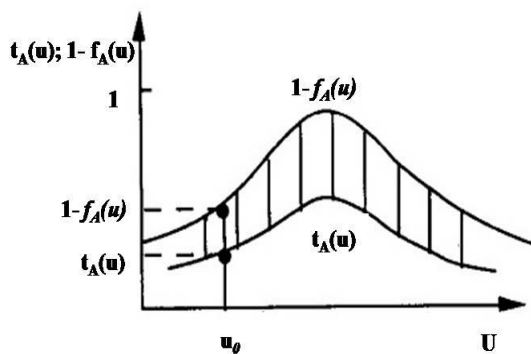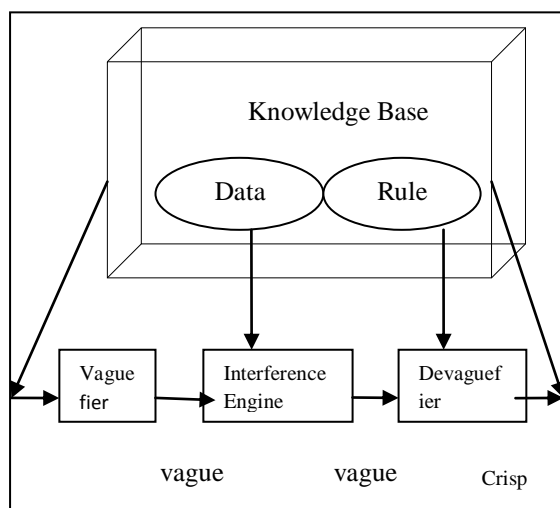
Fig. 1. vague set

Vague set controllers are rule-based controllers. The structure of the VC resembles that of a knowledge based controller except that VC utilizes the principles of vague set theory in its data representation and its logic. The basic configuration of the VC can be simply represented in four parts, as shown in the Fig. 2. [9,10].



Fig.2. schematic diagrams of the vague controller building blocks

## III.    Vague Set Based Controller Power System Stabilizer (VCPSS)

The initial step in designing the VCPSS is the determination of the state variables which represent the performance of the system. The input signals to the VCPSS are to be chosen from these variables. The input values are normalized and converted into vague variables. Rules are executed to produce a consequent vague region for each variable. The expected value for each variable is found by devaguefying the vague regions. The speed deviation ($\Delta \omega$) of the synchronous machine and its derivative ($\Delta \dot{\omega}$) are chosen as inputs to the VCPSS and the output (voltage) is the stabilizing signal. This signal is fed as one of the inputs to the excitation system.

In the present work five linguistic variables for each of the input and output are used which transform the numerical values of the input of the vague controllers to vague quantities. The linguistic variables are labeled as in the following TABLE I.

TABLE I.
Input and Output Linguistic Variables

| NB | Negative Big |
|----|--------------|
| NS | Negative Small |
| ZO | Zero |
| PS | Positive Small |
| PB | Positive Big |

The sugeno inference engine is used. The devagufication of the vague variables into crisp outputs is tested by using the sugeno-style.

Fig.3 shows MATLAB based simulation diagram of the proposed vague controller in the MATLAB environment.

The design structure and application of VCPSS in detail refer [11,12]
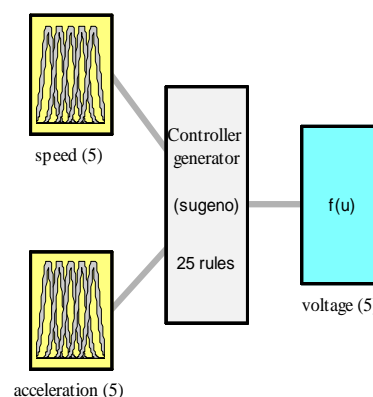


System Controller generator: 2 inputs, 1 outputs, 25 rules

Fig. 3. MATLAB simulation of  vague controller

## IV.    Adaptive Network Based Vague Inference System (ANVIS)

Adaptive Network based Vague Inference Systems works in the framework of adaptive systems to facilitate learning and adaptation. Such framework makes vague set based controller (VC) more systematic and less relying on expert knowledge.

An ANVIS works by applying neural learning rules to identify and tune the parameters and structure of a Vague Inference System (VIS). There are several features of the ANVIS which enable it to achieve great success in a wide range of scientific applications. The attractive features of an ANVIS include: easy to implement, fast and accurate learning, strong generalization abilities, excellent explanation facilities through vague rules, and easy to

incorporate both linguistic and numeric knowledge for problem solving.

According to the neuro-vague approach, a neural network is proposed to implement the vague system, so that structure and parameter identification of the vague rule base are accomplished by defining, adapting and optimizing the topology and the parameters of the corresponding neuro-vague network, based only on the available data. The network can be regarded both as an adaptive vague inference system with the capability of learning vague rules from data, and as a connectionist architecture provided with linguistic meaning. A typical architecture of an ANVIS, in which a circle indicates a fixed node, whereas a square indicates an adaptive node, is shown in Fig.4. This fig. shows input, output nodes and the hidden layers. There are nodes functioning as lower-upper bound membership functions (MFs) and rules.[13]

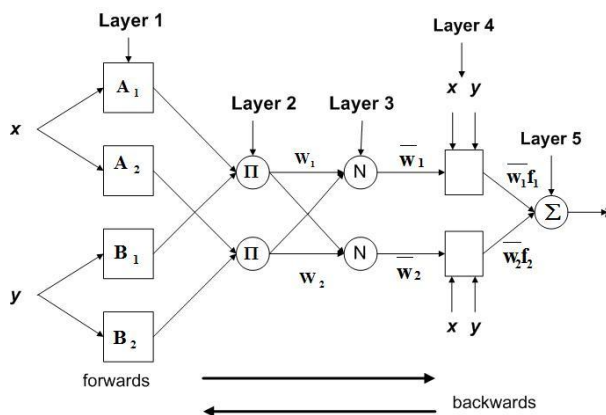Let us consider two-vague rules based on a first order Sugeno Type:



Fig.4. construction of ANVIS architecture

Rule 1: If $x$ is $A_1$ and y is $B_1$, then

$$f_1 = p_1 x + q_1 y + r_1 \qquad (3)$$

Rule 2: If $x$ x is $A_2$ and y is $B_2$, then

$$f_2 = p_2 x + q_2 y + r_2 \qquad (4)$$

Where x and y are the two crisp inputs, and $A_1$, $A_2$ and $B_1$, $B_2$ are the linguistic labels associated with the node function. ANVIS is composed of five functional layers, as shown in Fig.4. The functioning of each layer is described as follows

In layer 1, nodes (input nodes) contains lower-upper bound membership functions. All the nodes in this layer are square and adaptive nodes. A node lower bound (truth) membership function defined by:

$$O_i^1 = t_{A_i}(x) \qquad (5)$$

For i = 1, 2

Where $x$ is the input and $A_i$ is the linguistic label (large, small, etc.) associated with this node.

The output of this node specifies the degree to which the given $x$ satisfies the quantifier $A_i$.

Every node in layer 2 is a fixed node (non adaptive) which multiplies the incoming signals. Every node in this layer is a circle node (rule node). Each node output represents the firing strength of a rule. It means the degrees by which the antecedent part of the rule is satisfied and it indicates the shape of the output function for that rule. hence, the nodes generates the output by cross multiplying all the incoming signals:

$$O_i^2 = \omega_t^i = t_{A_i}(x) \times t_{B_i}(y) \qquad (6)$$

For i = 1, 2

Nodes in layer 3 are fixed nodes (average node). Every node in this layer is a circle node labeled N. The i$^{th}$ node calculate the ratio of the truth –false firing strength $(\varpi_t^i, \varpi_f^i)$ of the i$^{th}$ rule to the sum of all firing strengths of the rules:

$$\varpi_t^i = \frac{\omega_t^i}{\sum_{i=1}^{2} \omega_t^i} \qquad (7)$$

In layer 4, every node (consequent node) $i$ in this layer is an adaptive node or square node. This layer includes linear functions, which are functions of the input signals. It has the following output:

$$O_i^4 = \varpi_t^i f_i = \varpi_t^i (p_i x + q_i y + r_i) \qquad (8)$$

where $\{p_i, q_i, r_i\}$ is referred to as the consequent parameter set. They can also be trained using ANVIS learning algorithms. $\varpi_i$ is the output of layer 3.

The single node in the layer 5 is a fixed node (output node). It is labeled as $\sum$ , that computes the overall output as the summation of all incoming signals, i.e.

$$O_i^5 = \sum_i \varpi_t^i f_i \qquad (9)$$

The ANVIS hybrid learning algorithm is composed of a forward pass and a backward pass. In the forward pass, keeping constant the available values of the premise parameters set, functional signals go forward until layer three and the consequent parameter vector $\{p_i, q_i, r_i\}$ is identified by means of the least squares estimate (LSE), solving the over constrained simultaneous linear equations.

In the backwards pass, the error rates propagate backward and the premise parameters.

The ANVIS architecture is not unique. Some layers can be combined and still produce the same output.

## V.     Adaptive Vague Set Based Controller Power System Stabilizer (AVCPSS)

An Adaptive-Network based vague structure is employed to design an adaptive vague set based controller power system stabilizer (AVCPSS). The VCPSS considered, have two inputs that are components of the speed and its deviation. In this method, input parameters change to linguistic variable and suitable lower-upper bound membership functions should be chosen for them. Moreover, the rule base contains the vague if-then rules of Sugeno type, in which the output of each rule is a linear combination of input variables added by a constant term.

Initial parameters of lower-upper bound membership functions and IF-THEN rules are selected in a random manner and after training process the obtained MFs and rules are applied to power system as an AVCPSS.

## VI.     Result

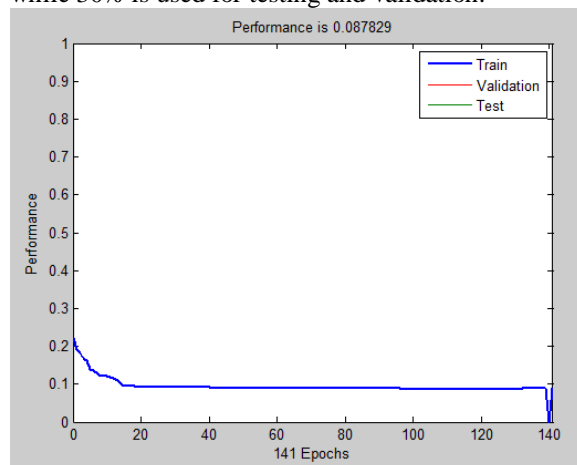System is trained using 70% of the data while 30% is used for testing and validation.



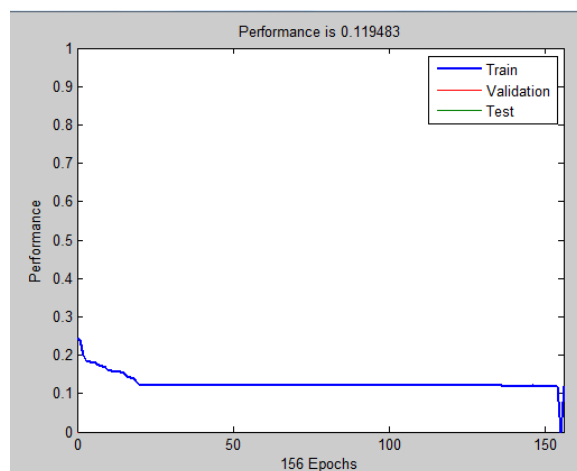Fig.5. Performance of training for vague set based system



Fig.6. Performance of training for fuzzy based system

The Fig.5 and Fig.6 shows the performance of training for vague set and fuzzy based system respectively. The classifications on the test set for each system is provide as follows :
(1) For Vague set based system:
Percentage Correct Classification     : 90.78%
Percentage Incorrect Classification    : 9.22%
MSE = 0.0873898          and
(2) For Fuzzy based system:
Percentage Correct Classification   : 84.62%
Percentage Incorrect Classification: 15.38%
MSE = 0.119489.

## VII.     Conclusion

In this paper ANVIS Neuro-Vague network were studied. Neuro-Vague systems combines the theory of artificial neural network and vague systems. The Artificial Neural networks provide effective learning methods and speed of computations whereas Vague theory allows working with ill-defined data in an effective manner.

The vague logic based adaptive power system stabilizer is also introduced. It systematically explains the steps involved in vague set based adaptive control design for oscillation damping in power system. The proposed controller provides a more robust control .

## VIII.     Acknowledgment

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