ANFIS BASED POWER FLOW CONTROL IN AC-DC MICRO-GRIDS USING MODIFIED UIPC

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Abstract : This paper introduces a ANFIS power flow control of interconnected AC-DC micro-grids in grid-connected hybrid micro-grids based on implementing a modified unified interphase power controller (UIPC). A typical grid connected hybrid micro-grid including one AC micro-grid and one DC micro-grid is considered. These micro-grids are interconnected using a modified UIPC. As the first contribution of this paper, the ANFIS controller, which uses three power converters in each phase is modified so that a reduced number of power converters is implemented for power exchange control between AC-DC micro-grids. The modified structure includes one power converter in each phase, named as the line power converter (LPC). And a power converter which regulates the DC bus voltage, named as bus power converter (BPC). The AC micro-grid is connected to the main grid through the LPCs which their DC buses are linked and can operate in capacitance mode (CM) or inductive mode (IM). ANFIS controller is used in the control structure of the LPCs. The ANFIS inference system is optimized based on H filtering method to reduce the errors in membership functions design. Thus as the second contribution to stabilize the DC link fluctuation. A new nonlinear disturbance observer based robust multiple-surface sliding mode control (NDO-MS-SMC) strategy is presented for DC side control of the BPC.

Index Terms - Hybrid micro-grid, UIPC, power controller, disturbance observer, multi-surface SMC, ANFIS controller.

I. INTRODUCTION:

The DC power resources such as photovoltaic (PV) system, fuel cells (FCs), energy storage systems (ESSs) as well as newly introduced DC loads such as programmable DC electronic loads and etc., The AC power resources such as wind turbines and etc. as well as the AC loads such as electrical motors. May be connected to the power systems through the AC micro-grids. In the future smart grids the AC and DC micro-grids including AC and DC power sources and loads are integrated as a hybrid system called the hybrid micro-grid actually. The AC and DC micro grids are interconnected the power converters. The power converters are usually connected in parallel to exchange larger amount of power and increases.

The ac micro-grid may contain wind turbine, diesel generator and AC bus. The whole hybrid grid – connected hybrid micro-grid. The DC micro-grid may include PV systems. ESSs and related loads. Micro-grid may be connected to the power system or isolated. The micro-grids have different dynamic characteristics such as different voltage levels, phases, frequency, and power fluctuation. A hybrid micro-grid may include several micro-grids for example two AC micro-grids and one DC micro-grids. In such a configuration with different dynamics using parallel-connected ILCs to exchange power between micro-grids is difficult and complicated since the micro-grids must be the same in order to avoid circulating current between parallel-connected ILCs. The transferred power among micro grids must be uniformly divided among parallel-connected ILCs with equal power ratings.

The power sharing performance of the parallel-connected ILCs is affected by change in the system parameters such as line impedance load variation etc.It may be isolated resulting in a major reduction in exchanged power. The distortions in the AC micro-grids, such as harmonics result in phase difference between ILCs which in turn causes voltage drop. The parallel-connected ILCs may operate in different power factors. A droop control-based hierarchical control method has been proposed in which the first control level has used a droop control. In the DC side. The proportional-integral (PI) controllers have been implemented whereas the proportional resonant (PR) controller has been used at the AC side. The second control level has modified the ripple. Which had been generated due to the first level control action. And the third control level has been used to connect the hybrid micro-grid with the utility.

II. PROPOSED UIPC DYNAMIC MODELING:

A. Proposed structure of UIPC

The DC link of all the VSCs in each phase are connected in parallel as described in [12], the VSCs with common DC links are inclined to make the common DC link voltage oscillatory when the output powers of VSCs change or when there is a disturbance on the system model. The link voltage fluctuation is a major concern in VSCs with a common DC links this issue has not been considered in [24].each phase just uses one power converter , named as LPCj, where j € {1,2,3} is the line number . These power converters through transformers Tj, inject the series voltage V_{se}^{r} And V_{se}^{i} are the real and imaginary parts of injected series voltage. The line impedance is$Z_{Lj} = R_{Lj} + jX_{Lj}$. The injected series voltage is actually a controlled voltage source with the following general form.

$$V_{se} = K_A V_{DC} \angle K_P \varphi_{se} \quad (1)$$

Where K_A *and* K_P are voltage amplitude and phase coefficients. The voltage amplitude coefficient K_A is indeed a function of pulse width modulation (PWM) and the phase coefficient K_P is ± 1 *and* φ_{se} is usually equal to $\frac{\pi}{2}$, the switches S_1 *and* S_2 are anti-parallel thyristors the injected voltage phase angle through the control system. At each instant, only one of these switches conduct at each phase, depending on the phase angle sign. The voltage phase coefficients K_P is equal to +1, the UIPC is in the inductive mode (IM) and S_1 is on and S_2 is off. In a similar way, when the phase coefficient K_P is equal to -1. The UIPC is in the capacitive mode (CM) and S_1 is off and S_2 is on. The exchanged power between the two AC busesV_1 *and* V_2. Can be controlled. There is only one BPC for all phases. The DC bus BPC is connected to the DC micro-grid. The BPC transformers T_{BPC} is also connected to one of the AC buses.

$$\varphi_{se}^{L} = \varphi_1 + \alpha_1 \quad (2)$$

$$\varphi_{se}^{C} = \varphi_2 + \alpha_2 \quad (3)$$

These angles are calculated by considering different operation modes of the UIPC, IM or CM. in equation (2)-(3) φ_{se}^{L}*and* φ_{se}^{C} are the phase angle of the voltage at the middle point of the transmission line. When the UIPC operates in IM and CM modes.

$$S = V_2\left(\frac{V_1 - V_2}{Z_L}\right) = (V_2 cos\delta_2 + jV_2 sin\delta_2)\frac{(V_1 cos\delta_1 + jV_1 \, sin\delta_1 - V_2 \, cos\delta_2 - jV_2 sin\delta_2)^*}{R_{L1} - jX_{L1}} \quad (4)$$

Where δ_1*and* δ_2 are the phase angles of the voltagesV_1 *and* V_2 . Equation (4) can be written as follows.

$$P = \frac{R_{L1} V_1 V_2 (coscos\ \delta_1\ coscos\ \delta_2 + sin\delta_1 sin\delta_2 + R_{L1} V_2^2) - X_{L1} V_1 V_2 (cos\delta_1 sin\delta_2 - sin\delta_1 cos\delta_2)}{R_{L1}^2 + X_{L1}^2} \quad (5)$$

$$Q = \frac{R_{L1} V_1 V_2 (cos\delta_1\ sinsin\ \delta_2 - sin\delta_1 cos\delta_2) + X_{L1} V_1 V_2 (coscos\ \delta_1 coscos\ \delta_2 + sinsin\ \delta_1 sinsin\ \delta_2 + X_{L1} V_2^2)}{R_{L1}^2 + X_{L1}^2} \quad (6)$$

In micro-grids $R_{L1} \gg X_{L1}$

$$P = \frac{V_1 V_2 (coscos\ \delta_1 coscos\ \delta_2 + sinsin\ \delta_1 sinsin\ \delta_2 + R_{L1} V_2^2)}{R_{L1}} = \frac{V_1 V_2}{R_{L1}}(cos\ cos\ (\delta_1 - \delta_2) + R_{L1} V_2^2 \quad (7)$$

$$Q = \frac{V_1 V_2 (coscos\ \delta_1 sinsin\ \delta_2 - sinsin\ \delta_1 coscos\ \delta_2)}{R_{L1}} = \frac{V_1 V_2}{R_{L1}} sin(\delta_2 - \delta_1) \quad (8)$$

$$V_1\angle\delta_1 - V_2\angle\delta_2 = (R_{L1} + jX_{L1})I + V_{se}\angle\varphi_{se} = (R_{L1} + jX_{L1})\frac{P - jQ}{V_2^r - jV_2^i} + (V_{se}^r + jV_{se}^i) + j\left(\frac{V_2^r(X_{L1}P - R_{L1}Q) + (R_{L1}P + X_{L1}Q)}{(V_2^r)^2 + (V_2^i)^2} + V_{se}^i\right) \quad (9)$$

In the micro-grids $R_{L1}P \ncong R_{L1}Q$

$$V_1\angle\delta_1 - V_2\angle\delta_2 = \left(\frac{V_2^r(R_{L1}P + X_{L1}Q)}{(V_2^r)^2 + (V_2^i)^2} + V_{se}^r\right) + jV_{se}^i \quad (10)$$

$R_{L1} P \gg X_{L1} Q$

$$V_1\angle\delta_1 - V_2\angle\delta_2 = \left(\frac{V_2^r + V_{se}^r((V_2^r)^2 + (V_2^i)^2)}{(V_2^r)^2 + (V_2^i)^2}\right) + jV_{se}^i \quad (11)$$

B. Proposed control strategy for LPCs:

The proposed UIPC structure includes two control subsystems LPCs control strategy and SMC based control strategy for BPC. The proposed control strategy for each LPC at each phase. As shown the injected series voltage and the line current are measured and scaled. Then, to obtain the fundamental components of these scaled signals, a band pass filter is used. The parameters of this filter are determined using MATLAB.

$$T_f = \frac{190.10s}{s^2 + 190.10s + 145321} \quad (12)$$

The root mean square (rms) values of the filtered signals are then obtained. The injected voltage error is given to the proposed optimized ANFIS controller. The phase of the injected voltage is measured using PLL. Then, the sign of this phase, which is actually K_P in equation (1). Is determined and based on this sign. It is concluded that the UIPC operates whether in IM mode or CM mode.

Thus, the appropriate phase shift is applied $+\frac{\pi}{2}$ for IM mode and $-\frac{\pi}{2}$ for CM mode. The switches s_1 *and* s_2 are enabled /disabled based on H∞ filtering design procedure. A DC link voltage signal is fed to the all LPCs control system for coordination. The error signal is then given to an optimal ANFIS. Therefore, the control signal for implementation in PWM unit is generated using these signals based on the PWM. The amplitude of the injected voltage K_A is controlled as given equation (1).

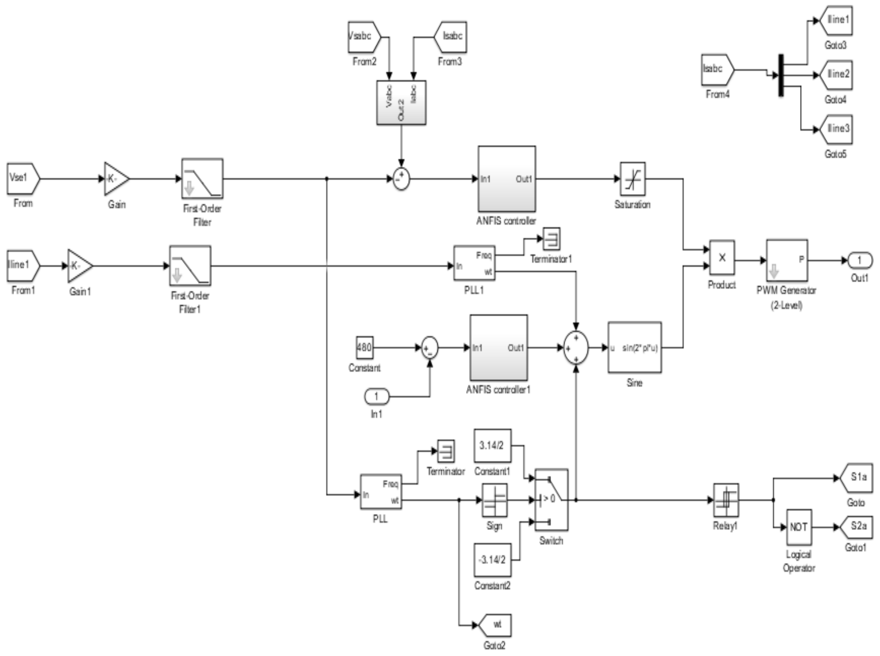

Fig: 1 proposed system ANFIS based controller

III. FUZZY LOGIC CONTROLLER DESIGN

In this section a separated fuzzy logic controllers (FLCs) are designed to replace the PI controllers and generate the reference's voltages in the synchronous frame. Generally, the fuzzy logic control is implemented in cases of nonlinear systems which have a degree of uncertainty. This technique is featured that it does not require an exact modeling or identification. The use of FLCs in improves UIPC. There are five variables for the input variables, defined in fuzzy sets: PB (positive big), PS (positive small), NS (negative small), NB (negative big), and ZE (zero error). Improve the dynamic performance and obtain more refined output. The asymmetric triangles are selected as the membership function in inputs in order to obtain high accuracy for steady state which is different from the conventional design. Fig.2 and 3 present the membership functions of the inputs and the outputs.

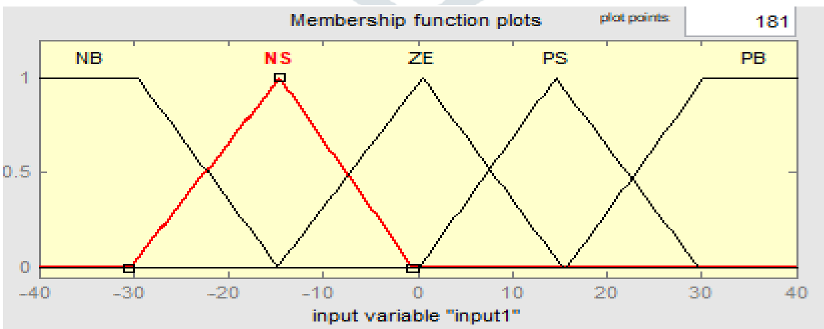

Fig: 2 membership function input 1

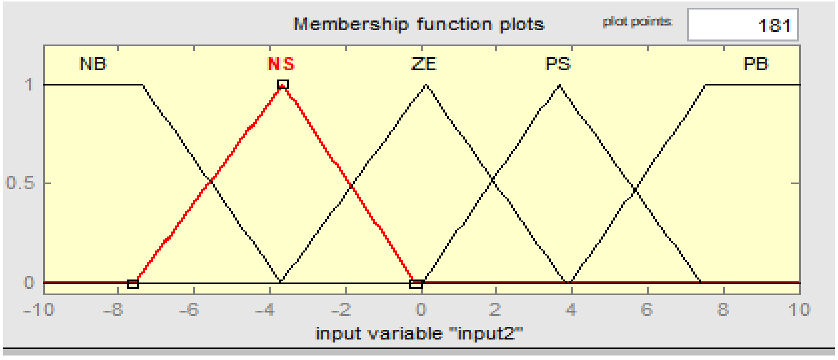

Fig:3 membership function input 2

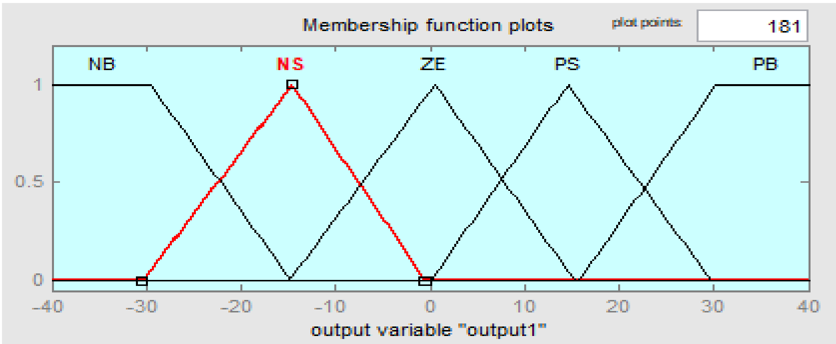

Fig: 4 membership function output

Table: 1 fuzzy Rules

E/CE	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

IV. ADAPTIVE NETWORK BASED -FUZZY INFERENCE SYSTEM

A versatile neuro-fluffy inference organize or adaptable framework based completely fluffy derivation network (ANFIS) is a type of fake neural machine that depends upon on Takagi-Sugeno fluffy acceptance arrange. The strategy changed into created in the mid-1990s. Since it arranges both neural frameworks and fluffy reason benchmarks, it could presumably catch gifts of each in a single shape. Its acceptance system looks at to a relationship fluffy IF-THEN includes a choice which cans possibly vague nonlinear limits. Along these lines, ANFIS is thought to be a comprehensive estimator. For using the ANFIS as a piece of an increasingly proficient and best way, you'll be in a situation to utilize the colossal parameters acquired by methods for generic figuring. ANFIS: Artificial Neuro-Fuzzy Systems.

ANFIS are a classification of versatile systems that are practically equivalent to fluffy derivation frameworks.

- ANFIS speak to Sugeno Tsukamoto fluffy models.
- ANFIS utilizes a half breed examining set of rules.

In the field of engineered insight neuro-fluffy implies blends of phony neural frameworks and fluffy reason. Neuro-fluffy hybridization achieves a half of and ½ of canny network that synergizes these methodology by means of the utilization of turning into an individual from the human-like pondering design of fluffy systems with the braking down and connectionist structure of neural frameworks. Neuro-fluffy hybridization is for the most part named as fuzzy neural Network (FNN) or Neuro-Fuzzy System (FNS) inside the composition. Neuro-fluffy systems (the more standard term is actualized from this time ahead) wires the human-like considering style fluffy systems the utilization of fluffy gadgets and a semantic model including a game plan of IF-THEN fluffy prerequisites.

The main aim of neuro-fluffy systems is that they might be great estimated approximately with the capacity to demand interpretable IF-THEN considerations. The great of neuro-fluffy systems comprises of clashing prerequisites in fluffy appearing: in inclination to precision. For all intents and purposes talk me, one of the homes wines. The neuro-fluffy in fluffy exhibiting examination challenge is isolated into two zones: semantic fluffy showing this is centered around interpretability, for the most extreme components the Mamdani form; and genuine fluffy exhibiting that is focused circular precision, by and large Takagi-Sugeno-Kang (TSK) variant. Communication to fuzzification, fluffy derivations and de-fuzzification through multi-layers feed-forward connectionist systems. It ought to be alluded to that interpretability of the Mamdani-type neuro-fluffy frameworks might be strange. To design the interpretability of neuro-fluffy frameworks, positive estimates need to be taken, wherein significant parts of interpretability of neuro-fluffy structures are additionally examined.

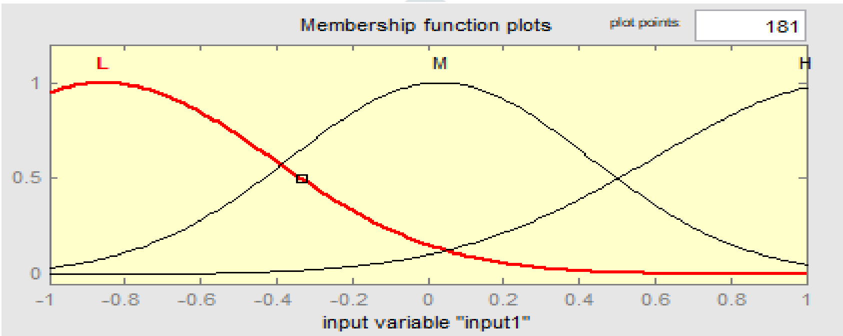

Fig: 5 membership function of input 1

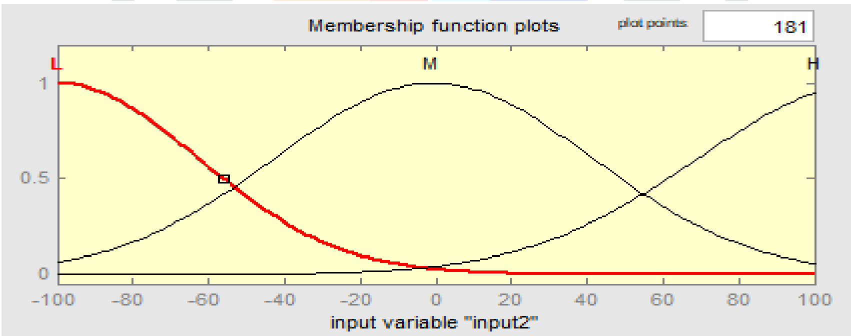

Fig: 6 membership function of input 2

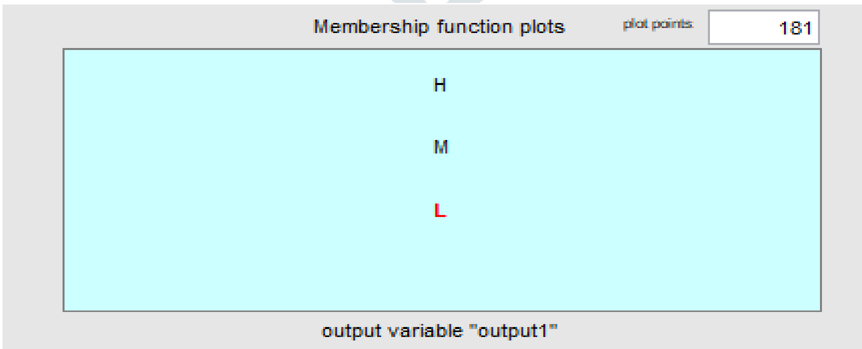

Fig: 7 membership function of output

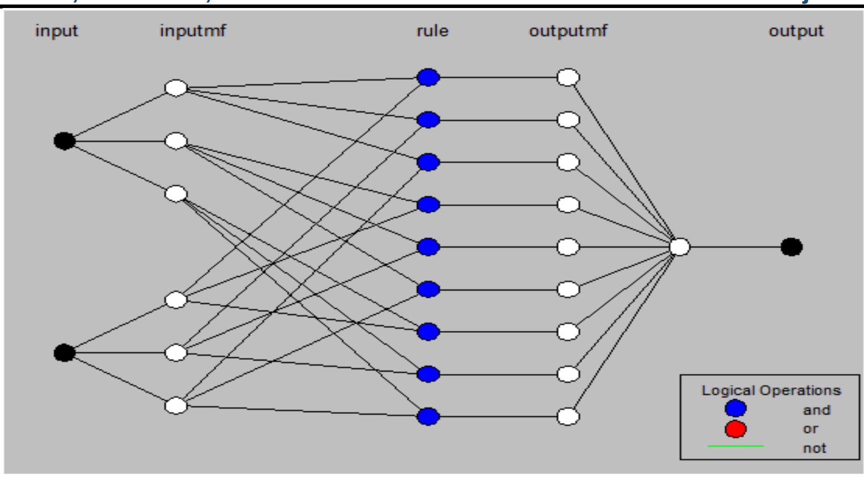

Fig: 8 ANFIS structure

Table: 2 ANFIS rules

Input-2 / Input-1	**L**	**M**	**H**
L	**L**	**M**	**H**
M	**M**	**H**	**H**
H	**H**	**H**	**H**

V. PROPOSED PI CONTROLLER:

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system.

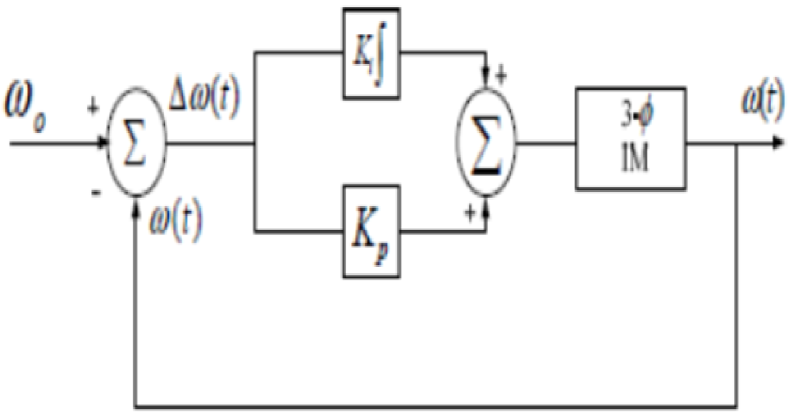

Fig: 9 PI controller

The controller output in this case is:

$$u(t) = K_P\, e(t) + K_i \int_0^t A\, e(t)dt \qquad (13)$$

Table: 3 Effects of changing control parameters

Parameter	Rise time	Over shoot	Settling time	Studystate error	Stability
K_p	Decrease	Increase	Small change	Decrease	Worse
K_i	Decrease	Increase	Increase	Significant Decrease	Worse
K_d	Minor Decrease	Minor Decrease	Minor Decrease	No change	If K_d small better

VI. MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

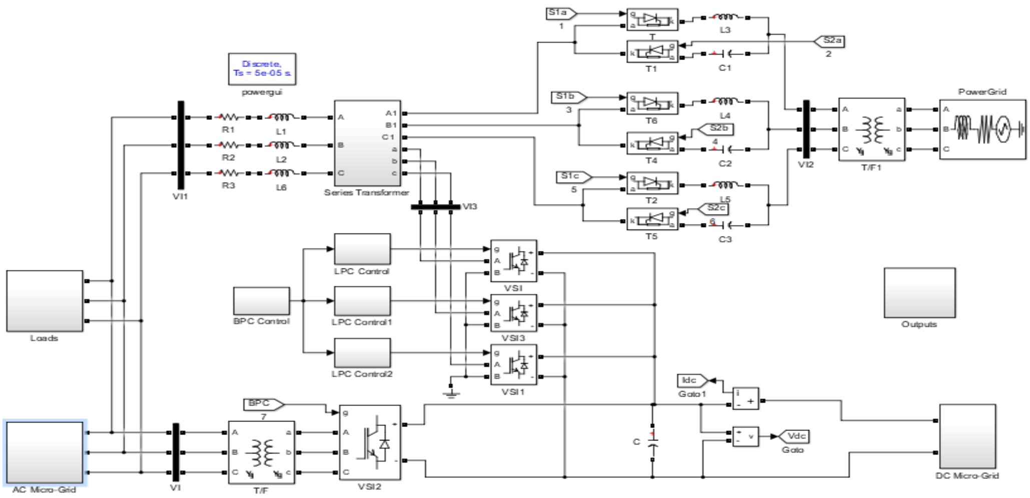

Fig: 10 simulation diagram

SIMULATION RESULTS:

A. Validation of modified UIPC model and power flow control between the AC micro-grid and main-grid:

The proposed control strategy has been simulated by using through Matlab/Simulink software. The following figures show the performance analysis of the proposed modified UIPC using controllers and SMC based DC link observer. The reference signal generated by the proposed control system as shown in fig: 11 time t=0.18s near the reference signal is generated by using ANFIS controller.

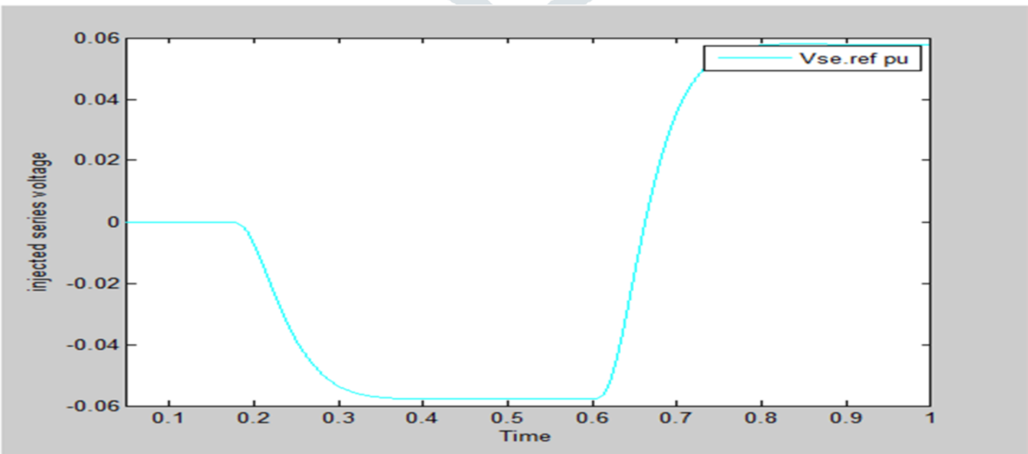

Fig: 11 Reference signal tracking performance of proposed UIPC

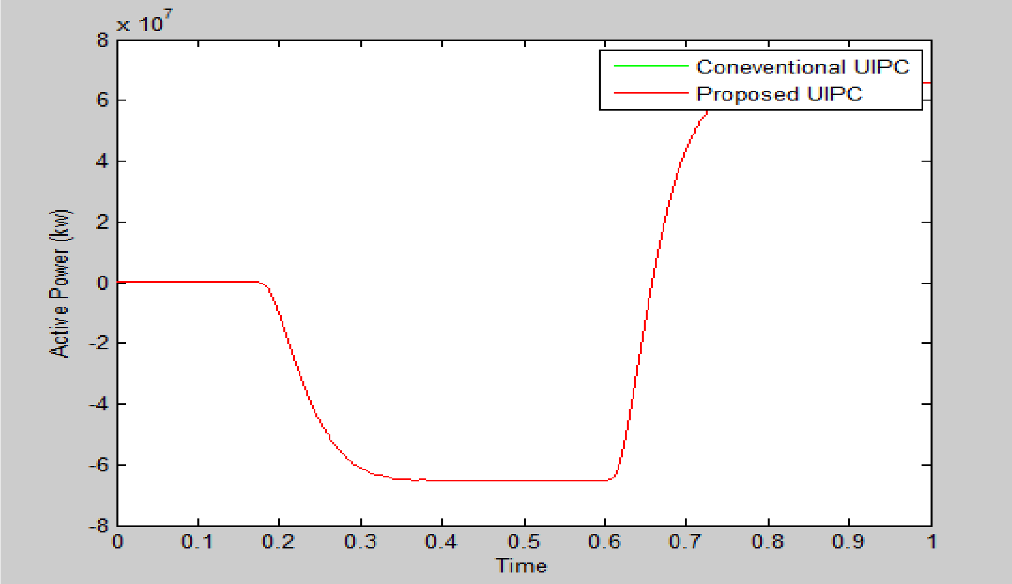

Fig: 12 Exchange power control between two AC microgrids using proposed and conventional UIPCs proposed UIPC

The exchanged power control performance when the conventional UIPC and Proposed UIPC are implemented initially the system is in the steady states and the UIPC is deactivated and no series voltage is injected in the AC side. Only one of the desiel generator is activated.untill time t=0.0018s

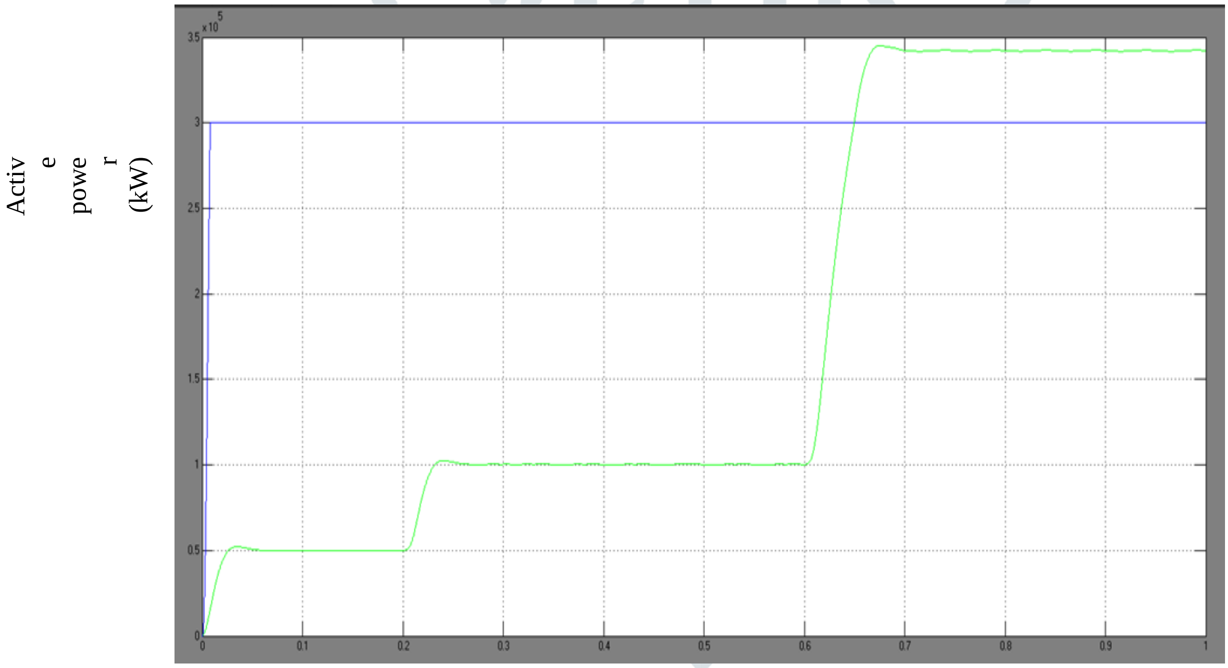

Fig: 13 generation in each micro-grid

The DC link of the proposed UIPC is connected to the DC micro-grid and this is one of the main features of the proposed structure. The DC link of the BPC is controlled using the proposed NDO-MS-SMC. As show in above figure the power flow is from the DC micro-grid to the AC side maintain the exchanged power constant between the AC micro-grid and main-grid.

A. Power flow control from DC micro-grid to AC micro-grid:

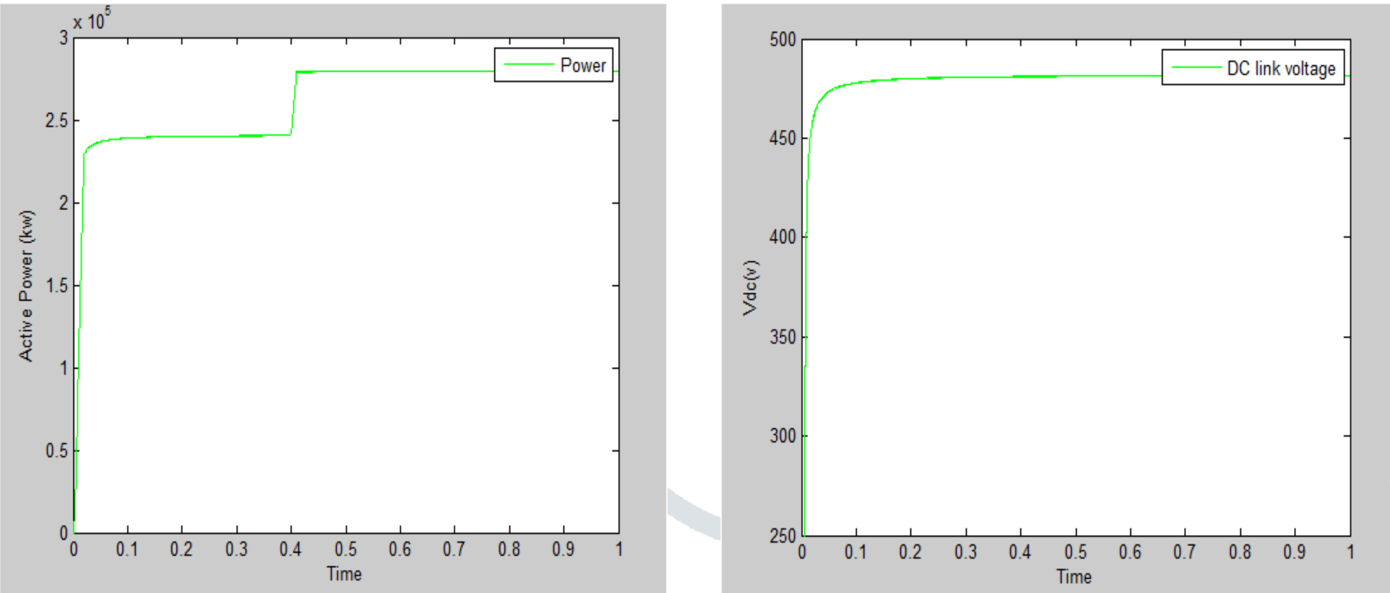

Fig: 14 DC link voltage when 40 kW is demanded from the AC side.

In above fig. 14 shown, the DC link active power increases to 280 kw to supply the AC side. The proposed NDO-MS-SMC strategy is able to overcome the problems of voltage fluctuations. The steady state voltage is 481 and settling time is t=0.4 sec in DC link voltage. The peak voltage at transient state (v) is 481.15 by using ANFIS controller.

B. Disturbance rejection performance and stability proof:

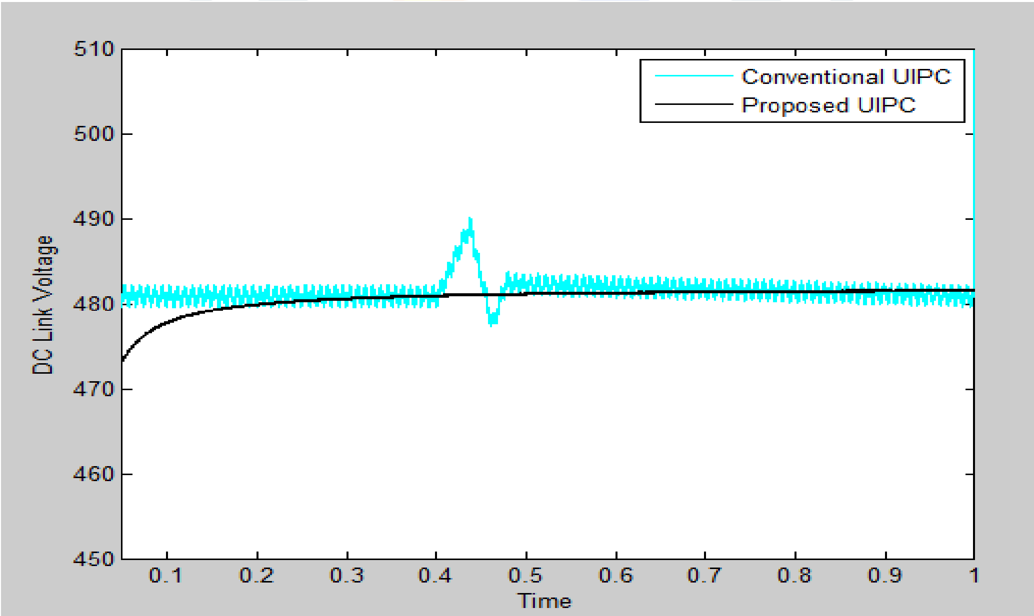

Fig: 15 performance of the proposed UIPC when the disturbances on the system model

As show in above fig: 15 to stable the robust stability and disturbance rejection performance the time variable signal is considered as disturbance on avoided to by using ANFIS controller. The conventional UIPC brings many oscillations with very high overshoots whereas the proposed UIPC equipped with the new control strategy has better performance and keep the system stable as well.

VII. CONCLUSION:

This paper deals with the improved UIPC based on ANFIS controller and Sliding mode controller. The power exchange control performance between AC and DC micro-Grids. This algorithm has been designed to overcome different drawbacks and problems concerning to ANFIS controller.

Table: 4 Comparison of Fuzzy control and ANFIS control Performance of Parameters

Parameters	Fuzzy control	ANFIS controller
Steady State Voltage	480	481
Peak Voltage at transient state (v)	490.2v	481.15
Settling time(sec)	0.45s	0.4 sec
DC Voltage Ripple (%)	5.25%	1.36%

APPENDIX:

Table: 5 System Parameters

Parameter	INV-1
P_{nom}	50kw
V_{nom}	400v
R_s	0.00076 pu
L_s	0.71 pu
L_r	0.156 pu
L_m	2.9pu
j	3.1s

REFERENCES:

[1] Run fan Zhang, Branislav Hredzak, "Distributed Finite-Time Multi-Agent Control for DC Microgrids with Time Delays", IEEE Transactions on Smart Grid, Early Access, 2018.
[2] Kumar Utkarsh, et al, "Distributed Model-predictive Real-time Optimal Operation of a Network of Smart Microgrids", IEEE Transactions on Smart Grid, Early Access, 2018.
[3] Haifeng Qiu, et al, " Bi-level Two-stage Robust Optimal Scheduling for AC/DC Hybrid Multi-microgrids", IEEE Transactions on Smart Grid, Early Access, 2018.
[4] Pengfeng Lin, et al, "A Distributed Control Architecture for Global System Economic Operation in Autonomous Hybrid AC/DC Microgrids", IEEE Transactions on Smart Grid, Early Access, 2018.
[5] Daniel E. Olivares, et al, "Trends in Micro-grid Control", IEEE Transactions on Smart Grid Volume: 5, Issue: 4, pp. 1905 – 1919, 2014.
[6] Jongwoo Choi, et al, "Robust Control of a Microgrid Energy Storage System using Various Approaches", IEEE Transactions on Smart Grid, Early Access, 2018.
[7] Daniel K. Molzahn, et al, "A Survey of Distributed Optimization and Control Algorithms for Electric Power Systems", IEEE Transactions on Smart Grid, Early Access, 2018.
[8] Cuo Zhang, et al, "Robustly Coordinated Operation of a Multi-Energy Microgrid with Flexible Electric and Thermal Loads", IEEE Transactions on Smart Grid, Early Access, 2018.
[9] Samrat Acharya, et al, "A Control Strategy for Voltage Unbalance Mitigation in an Islanded Microgrid Considering Demand Side Management Capability", IEEE Transactions on Smart Grid, Early Access, 2018.
[10] Pengcheng Yang, et al, "A Decentralized Coordination Control Method for Parallel Bidirectional Power Converters in a Hybrid AC/DC Microgrid", IEEE Transactions on Industrial Electronics, Early Access, 2017.
[11] Ignacio Gonzalez-Prieto, et al, "Impact of Post fault Flux Adaptation on Six-Phase Induction Motor Drives With Parallel Converters", IEEE Transactions on Power Electronics, Volume: 32, Issue: 1, pp. 515 – 528, 2017.
[12] Xiaonan Lu, et al., "Control of Parallel-Connected Bidirectional AC-DC Converters in Stationary Frame for Microgrid Application", IEEE, Energy Conversion Congress and Exposition (ECCE), 2011.

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