

ANFIS Controller Based Synchronous Power Controller with Flexible Droop Characteristics for a Renewable Power Generation Systems

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Abstract

In this paper presents the expanding measure of renewable power generation systems is a testing issue for the control and operation of the electrical systems. One of the principle issues is their absence of idleness, which is turning into a more prominent issue as much as the share of the power plants in view of customary synchronous generators gets decreased. In such manner the new system codes request that these plants give new functionalities, for example, the frequency support and dormancy imitating.

A synchronous power controller for system connected converters is proposed as a decent answer for the renewable generation systems with energy storage. It gives latency, damping and adaptable droop qualities. Not quite the same as the reliable replication of the swing condition of synchronous machines, an option control structure is proposed, by which the damping and inherent droop slope can be series freely to meet the requirements in both progression and frequency directions.

The Proposed tri-port technology with ANFIS is developed in MATLAB/SIMULINK environment and the results are proven to be successful in damping & droop characteristics' are addressed and damping and droop characteristics are done separately and have to capability to make better for synchronous power controller nearby future

I. INTRODUCTION

Customary generation plants in view of renewable energy sources (RES) go about as network bolstering systems, which convey the greatest power from the essential source to the

grid. As much as the infiltration of the RES generation plants expands, the lacking latency in the entire system could undermine its working soundness. Hence, the control targets and flow of the system connected converters should be switched in accordance with take more duties in grid supporting issues, for example, dormancy copying, frequency direction and voltage regulation.

The droop control procedure has been actualized in the control of grid connected converters. Despite the fact that the external droop circles permit the grid connected converters to modify the relentless state control infusion as per the request of the network, the transient practices of these Converters are sufficiently bad. The absence of dormancy is still a downside, which can't be enhanced by load control without risking the steady operation of a grid connected converter.

An answer for enhance the flow of the converters is to indicate the properties of the system connected converters in a manner that it demonstrations like a synchronous generator (SG), as is proposed in. It is an approach that has been drawing a considerable measure of interests in the current years. This pattern is started by the way that traditional grid synchronization calculation like Phase-locked loop (PLL) presents not idleness attributes, and the elements of any supporting technique is influenced by the intrinsic progression of the PLL. Additionally, a PLL may negatively affect the control execution under powerless ac networks.

A control usage conspires for the copying of SG is proposed. In which the circle

filter of the traditional PLL is altered to imitate the dormancy and damping qualities. Other comparable outline or recommendations fusing inactivity and damping in a PLL can be found. In view of the methodology, the dormancy impact is just connected to the system frequency, and does not basically exist while responding to the power input varieties. At that point the bothers in the dc side will be straightforwardly transmitted to the air conditioner side without latency. What's more, the dormancy impact does not exist in island operation in view of this sort of outline.

Another execution technique for copying SG is proposed and broke down, in which the PLL is substituted by a dynamic power synchronization loop. Despite the fact that this technique has indicated preferences in the interconnection of feeble ac matrices, the inactivity and swaying damping are not particularly tended to, and it must be switched to a PLL-based vector current control under extreme ac deficiencies.

A torque synchronization loop is outlined considering inertia and damping attributes. A comparable procedure is additionally embraced. The creators propose a synchronous power controller displaying idleness and damping attributes, and especially a virtual permission structure is proposed. The creators demonstrate that the latency can likewise be executed in the micro grid droop controller, making utilization of the primary request low-pass filter which is generally utilized just to damp the estimation clamor. The previously mentioned outlines join the swing condition innately in the power directing circle, in this manner the power synchronizing impact will be available in both grid connected or island operation. By and by, the damping impact and the power-frequency droop incline are obliged by each other. Because of this, a great parameter for the droop highlight may prompt to a deficient damping, and in the

different way, damping parameter could offer ascent to an undesired droop slant. Then again, since the droop attributes are normally consolidated in the power controlling circle, a settled power control can't be specifically accomplished regardless of the possibility that it is required in a few applications. The creators propose to utilize an extra PI controller with a virtual droop to modify the damping filter to accomplish a settled power control if necessary, however the request of the shut circle switch capacity will build, in this manner the dynamic investigation and tuning of parameters turn out to be more complex.

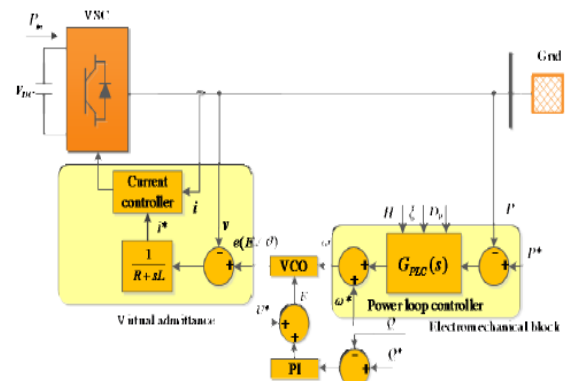


Fig. 1. The overall control scheme of synchronous power controller

This project proposes a synchronous power controller with inertia, damping and flexible droop characteristics connected converters. Contrasted and the current systems, damping and droop attributes are especially tended to, while the inactivity highlight is kept up. The damping execution is critical for the nearby solidness and flow of the RES-based generation systems. Furthermore, the droop attributes are important to satisfy the required frequency support. Along these lines, rather than tuning a solitary parameter to locate a decent tradeoff between both damping and droop qualities, a power circle controller is proposed to design damping and droop attributes independently. Also, an express connection among the controller gain, latency, damping coefficient and droop slope is given, and in this way the proposed strategy makes an

adaptable control worldview conceivable in which the controller increases can be adaptive.

II. OVERALL CONTROL STRUCTURE

The proposed control circle controller depends on the general synchronous power control (SPC) motorizing appeared in Fig. 1. This control plan is predominantly portrayed by two hinders, the electromechanical piece and the virtual permission square, which are separately depicted. Notwithstanding the control plot appeared in Fig. 1, external circles can be included. Contingent upon the prerequisites of the network and the design and control system at the dc side, the external circles can differ. Regularly a Q-V hang controller is included for feeble lattice support and island system shaping. What's more, considering the constrained power save from the dc side, an external P-Vdc hang control can likewise be incorporated as an expansion to the P-f qualities.

In view of the general control structure, the inactivity can be basically fused in the electromechanical control circle by legitimately outlining the power circle controller.

As appeared in Fig. 1, the power circle controller creates a virtual synchronous frequency ω , which is then coordinated to a stage flag θ . consolidating the stage flag θ and the greatness flag E (produced by the receptive power controller), the virtual electromotive compel e will be created by the Voltage Controlled Oscillator (VCO). For this situation a PI controller is executed in the responsive power control circle.

The virtual permission structure received is chosen as the structure of the internal control circles, which is appeared in Fig. 2. It is a copying of the output impedance of SG. This piece assumes a key part in load sharing and shows a characteristic voltage

greatness hang highlight for network voltage bolster.

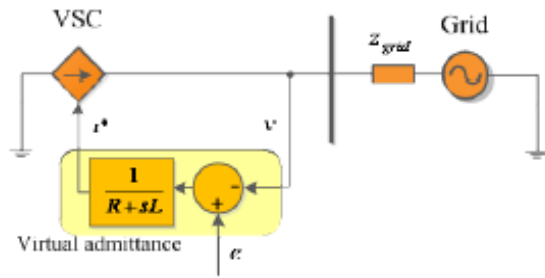


Fig. 2. Virtual admittance emulating the electrical characteristics of synchronous machines.

Contrasted and the outstanding virtual impedance structure, the virtual permission structure copies the output impedance without prompting to the troubles in usage. The principle focal points lay on the viability for the entire scope of consonant frequencies and the straightforwardness in the inward circle execution.

As indicated by the electrical qualities of the synchronous machines, the produced dynamic power can be approximated to (1), considering that the output impedance of SG is predominantly inductive.

$$\Delta P = P_{max} \Delta \delta \quad (1)$$

Where ΔP is the incremental generated power and $\Delta \delta$ is the incremental phase-angle difference between the virtual electro-motive power e and the grid voltage v in each phase. The admittance gain is expressed as,

$$P_{max} = \frac{EV}{X} \quad (2)$$

Where E and V are respectively the RMS values of e and v , and X the value of the reactance provided by the virtual admittance. Based on (1), the inner control loops can be simply modeled as an admittance gain since it has much faster dynamics compared with outer

loops. So it avoids the complexity in the analysis of power loop.

III. ELECTROMECHANICAL BLOCK

As indicated by the control plot appeared in Fig. 1, the dynamic power controlling circle can be displayed as appeared in Fig. 3, where the power circle controller GPLC(s) is composed in this area. The synchronization system of the SPC-based converter is like the one of a SG. Regardless of the possibility that the network voltage edge θ lattice is obscure, the synchronous precise speed ω can simply be changed in accordance with in like manner move the heap edge δ . along these lines the dynamic power is directed.

As the fundamental concentration of this paper, a power circle controller is proposed. In the accompanying, the current systems that for all intents and purposes actualize the swing condition of SG are broke down to start with, and the limits of the current strategies are appeared. At that point an option controller is proposed, and the numerical relationship between the trademark parameters and the control parameters is shown.

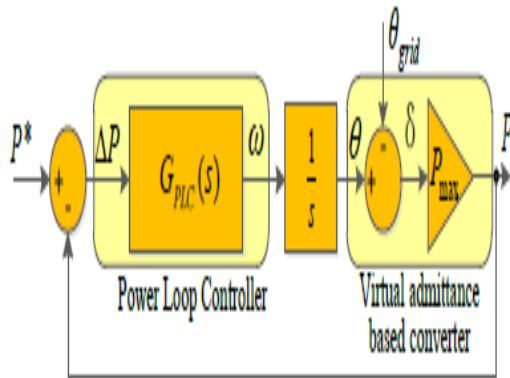


Fig. 3. Modeling of active power control loop converter

A. Mechanical Power Loop Controller

The SG swing equation can be expressed as (3) in terms of power, for small

signals of the rotor angular frequency ω around the synchronous frequency.

$$P_{mech} - P_{elec} = \omega_s (Js + D) \omega \quad (3)$$

In (3), P_{mech} is the information mechanical power, P_{elec} the output electrical power, ω_s the synchronous frequency, J the snapshot of inactivity and D the damping parameter. Despite the fact that the damper twisting of SG can give the damping impact, it is moderately restricted. Considering this reality, the damping of the power circle can be enhanced and advanced for control of grid connected converters. Subsequently, the damping term is considered and additionally the latency.

In view of the swing condition, the type of GPLC(s) can be outlined as appeared in (4), which is referenced as mechanical power circle (MPL) controller in this paper.

$$G_{PLC}(s) = \frac{1}{\omega_s (Js + D)} \quad (4)$$

According to (4), the resulting closed-loop transfer function is obtained and shown in (5a).

$$\frac{P}{P^*}(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \quad (5a)$$

$$\xi = \frac{D}{2} \sqrt{\frac{\omega_s}{JP_{max}}} \quad (5b)$$

$$\omega_n = \sqrt{\frac{P_{max}}{J\omega_s}} \quad (5c)$$

Equation (5a) is given in the particular shape as a relationship of the second request parametric switch work, for which the time reaction is characterized by the parameters ω_n and ξ . Besides, ω_n and ξ are likewise connected to the damping and idleness parameters of the SG swing condition through (5b) and (5c).

To ensure the neighborhood strength of the system, ξ must be determined more noteworthy than zero.

Rather than utilizing the snapshot of idleness J to assign the latency attributes, the inactivity consistent H is regularly received, which is characterized in (6), which means the time it takes to quicken the rotational speed from zero to ω_s utilizing full power S_N .

$$H = \frac{J\omega_s^2}{2S_N} \quad (6)$$

For analyzing the dynamics of the power control circle, the reaction to frequency unsettling influences likewise should be considered. In the demonstrating, the matrix frequency can be connected to the lattice stage edge by an integrator. As per Fig. 3, taking ω_g as the variable while taking P as the capacity, the connected transfer function (P-f response) is shown in (7).

$$\frac{\Delta P}{\Delta \omega_g}(s) = \frac{-P_{max}(s + 2\xi\omega_n)}{s^2 + 2\xi\omega_n s + \omega_n^2} \quad (7)$$

It is seen from (7) that the MPL controller incorporates an intrinsic P-f droop feature. If the droop ratio D_P is defined as (8), which describes the steady-state power variation caused by the grid frequency change,

$$D_P = \left(\frac{2\pi}{1000}\right) \cdot \left| \frac{\Delta P}{\Delta \omega_g}(0) \right| \text{ kW/hz} \quad (8)$$

then combining (7) and (8), the intrinsic droop ratio of the MPL controller $D_{P(MPL)}$ is expressed in (9).

$$D_{P(MPL)} = \frac{4\pi\xi P_{max}}{1000\omega_n} \quad (9)$$

It is seen that the MPL controller realizes a constant power synchronizing conduct the length of the lattice frequency

digresses from the ostensible esteem. Be that as it may, the hang proportion DP is obliged by the dormancy and damping parameters that prompt to a tradeoff in the parameters setting.

B. Boundaries of the MPL Controller

To further demonstrate the limitations of the MPL controller in parameters tuning, the matrix frequency deviation rate that concentrates the full evaluated control from the converter is utilized as the marker of the hang attributes, which is spoken to by $1/R$. The connection amongst DP and $1/R$ is appeared in (10).

$$\frac{1}{R} = \frac{2\pi S_N}{D_P \omega_g} \quad (10)$$

Then the interaction among inertia, damping and droop slope defined by the MPL controller is obtained as written in (11), which is derived combining (5c), (6), (9) and (10).

$$\frac{1}{R}(\text{MPL}) = \frac{1}{2\xi} \sqrt{\frac{X_{pu}}{2H\omega_g}} \quad (11)$$

Where X_{pu} represents the per-unit value of the reactance of virtual admittance and is expressed in (12).

$$X_{pu} = \frac{S_N}{P_{max}} \quad (12)$$

Equation (11) shows the interaction among H , ξ , X_{pu} and $1/R$. And since the values of H and X_{pu} can be pre-fixed respectively considering the design requirement, the challenge mainly lies in the restriction between ξ and $1/R$.

This restriction is visualized in Fig. 4, where H is specified to 2, 11 and 20 respectively in three cases. The grid nominal frequency is set to 50 Hz and X_{pu} is set to 0.3 to specify the model.

As appeared in Fig. 4, once the damping coefficient ξ is tuned and fixed, the hang incline will be settled, as well. However then again, the hang incline should be

indicated considering the frequency variety of the utility lattice and the power save of the era plants.

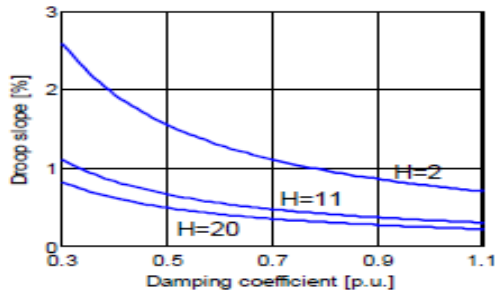


Fig. 4. The relation between the droop slope $1/R$ and the damping coefficient ζ .

For conventional synchronous generators, a commonplace scope of hang incline is $4\% < 1/R < 5\%$. In any case, for RES-based era plants, $1/R$ may must be more noteworthy considering the power save that is in fact and financially doable. In the situations appeared in Fig. 4, $1/R$ is underneath 3% . On the off chance that $1/R$ is required to be more prominent, ζ must be diminished, which undermines the damping execution.

This issue won't exist if the matrix is commanded by the converters controlled with the MPL controllers, since a little estimation of $1/R$ prompts to more grounded impact in contradicting frequency deviation. Notwithstanding, if the aggregate era is commanded by conventional synchronous generators, the frequency variety in the network can bring about regular immersion or low power quality infusion of the era units that have a little estimation of $1/R$.

C. Configurable Natural Droop Controller

In order to achieve a good grid interactive performance in which the droop slope can be specified independent of the damping parameter, a power circle controller with latency, damping and flexible droop attributes is proposed as appeared in Fig. 5.

Other than the implementation of the swing equation of a SG, a droop branch is

included in parallel for controlling the P - f droop slope in steady state. In this way it adjusts the offset of the power transfer function by introducing a new degree of freedom. The structure of the droop branch is developed in the way that it shares the same denominator with the transfer function of the swing equation. In this manner the order of the power regulating loop does not increase. In a practical implementation the integrators in the controller can be discretized using the Tustin trapezoidal method for an accurate equivalence.

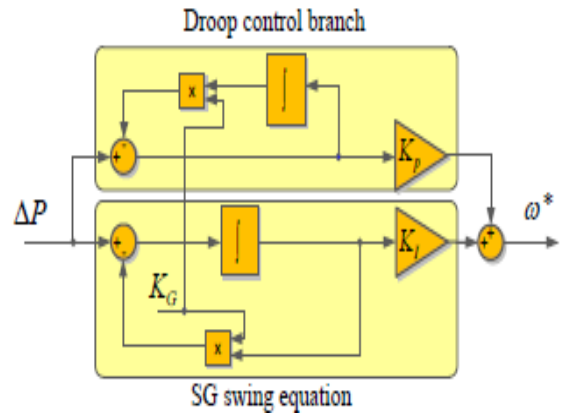


Fig. 5. The proposed power loop controller.

The transfer function of the proposed controller is generalized as written in (13), which is referred as configurable natural droop (CND) controller in this paper.

$$G_{PLC}(s) = \frac{K_P s + K_I}{s + K_G} \quad (13)$$

Contrasted and the MPL controller, the CND controller gives an extra level of flexibility without expanding the request of the power directing switch work. Furthermore, it gives a characteristic P - f hang highlight which can be designed in-ward to the dormancy and damping parameters.

Substituting the power circle controller obstruct in Fig. 3 with the expression (13), the subsequent shut circle switch capacity is appeared in (14a). The damping coefficient and characteristic frequency are separately communicated in (14b) and (14c).

$$\frac{P}{P^*}(s) = \frac{(2\xi\omega_n - K_G)s + \omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \quad (14a)$$

$$\xi = \frac{P_{max}K_P + K_G}{2\omega_n} \quad (14b)$$

$$\omega_n = \sqrt{P_{max}K_I} \quad (14c)$$

Even though (14a) has an alternate expression in the numerator contrasted and the standard second-order parametric switch work, the denominator of the system is the same. In this way, keeping in mind the end goal to put the shut circle posts in the left half plain to ensure the steadiness, ξ still must be indicated more noteworthy than zero.

The P-f reaction of the CND controller is appeared in (15),

$$\frac{\Delta P}{\Delta \omega_g}(s) = \frac{-P_{max}(s + K_G)}{s^2 + 2\xi\omega_n s + \omega_n^2} \quad (15)$$

Where (16) is obtained.

$$D_{P(CND)} = \frac{2\pi K_G}{1000 K_I} \quad (16)$$

As indicated by (14b), (14c) and (16), by determining the control parameters KP, KI and KG, the idleness, damping and hang attributes can be individually given. In addition, the normal frequency ω_n can be meant the latency consistent H by joining (5c) and (14c) to liken the ω_n from two cases. Alternatively, DP can be set to zero if the plant is allocated to have a settled power control.

IV. CONTROL PARAMETERS SETTING

The control parameters KP, KI and KG can be obviously set by the contribution of DP, H and ξ . Inferable from the express connection between the controller additions

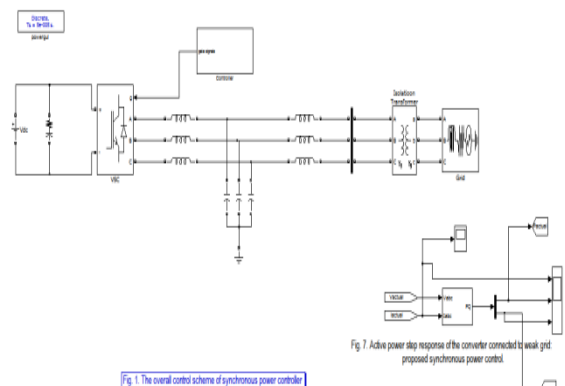
and trademark parameters, the controller can without much of a stretch be made versatile as per the auxiliary control, and an adaptable control worldview gets to be distinctly conceivable. In the usage the calculation for ascertaining the control parameters in view of (14b), (14c) and (16) can be installed in the converter controller, however might be initiated when the auxiliary orders are refreshed.

As specified in the previous segment, DP is the hang proportion that should be resolved in light of the frequency variety of the utility matrix and the practical power save. H can be assigned considering the dormancy consistent of the SG that has a similar power level. Furthermore, the damping coefficient ξ can be set considering the normal esteem range to make a steady and under-damped system. $10 \ll \xi$

So as to further tune ξ , the investigation on progression is done in view of the scientific move capacities given in the previous area. Unitary stride information is given to the shut circle switch work (14a), and the impact of ξ on the settling time and overshoot of the time reaction can be ascertained.

Proposed results

CASE-I



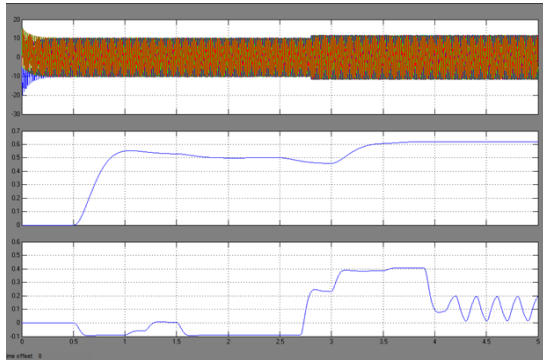


Fig.6. Active power step response of the converter connected to weak grid: The proposed synchronous power control. b)Active Power c)Reactive Power
CASE-II

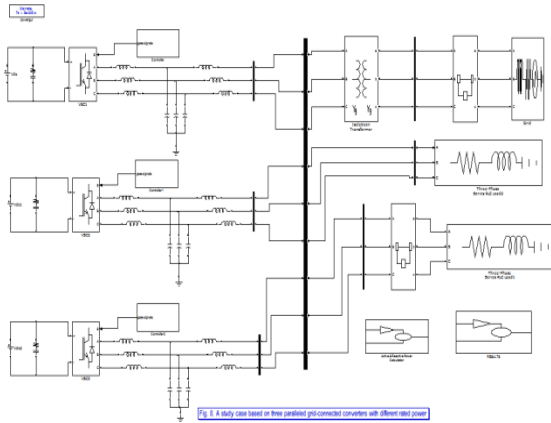


Fig. 7. The islanding action and load variations of a three-port system.

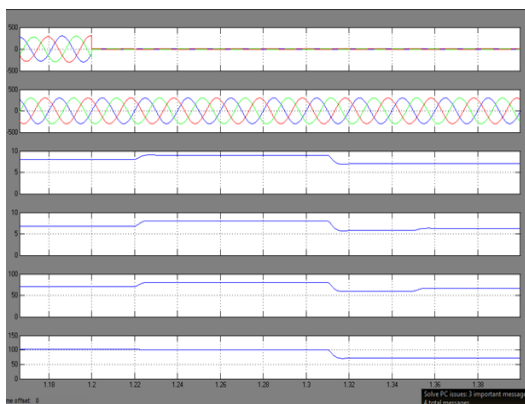


Fig. 8. The islanding action and load variations of a three-port system. a)Grid Voltage b)Load Voltages c) Converter1 active Power d) Converter2 active power

e) Converter3 active Power f)Load active Power

Extension ANFIS Controller

Today control systems are usually described by mathematical models that follow the laws of physics, stochastic models or models which have emerged from mathematical logic. A general difficulty of such constructed model is how to move from a given problem to a proper mathematical model. Undoubtedly, today's advanced computer technology makes it possible; however managing such systems is still too complex.

These complex systems can be simplified by employing a tolerance margin for a reasonable amount of imprecision, vagueness and uncertainty during the modeling phase. As an outcome, not completely perfect system comes to existence; nevertheless in most of the cases it is capable of solving the problem in appropriate way. Even missing input information has already turned out to be satisfactory in knowledge-based systems.

Fuzzy logic allows to lower complexity by allowing the use of imperfect information in sensible way. It can be implemented in hardware, software, or a combination of both. In other words, fuzzy logic approach to problems' control mimics how a person would make decisions, only much faster.

Usually fuzzy logic control system is created from four major elements presented on Figure 1: fuzzification interface, fuzzy inference engine, fuzzy rule matrix and defuzzification interface. Each part along with basic fuzzy logic operations will be described in more detail below.

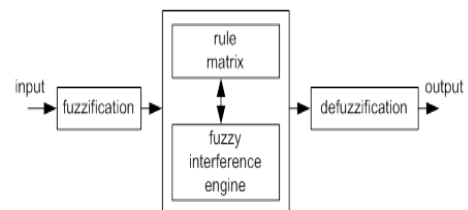


Figure 9. Fuzzy logic controller

ANFIS controller is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. ANFIS is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra.

Advantages of ANFIS Controller over PI Controller

Usage of conventional control "PI", its reaction is not all that great for non-linear systems. The change is striking when the controls with ANFIS are utilized, acquiring a superior dynamic reaction from the system.

Or

The PI controller requires exact direct numerical models, which are hard to get and may not give tasteful execution under parameter varieties, load unsettling influences, and so forth. As of late, ANFIS Controllers have been presented in different applications and have been utilized as a part of the power devices field. The benefits of ANFIS controllers over ordinary PI controllers are that they needn't bother with a precise scientific model, Can work with uncertain information sources and can deal with non-linearities and are more powerful than traditional PI controllers.

Simulation Results

CASE-I

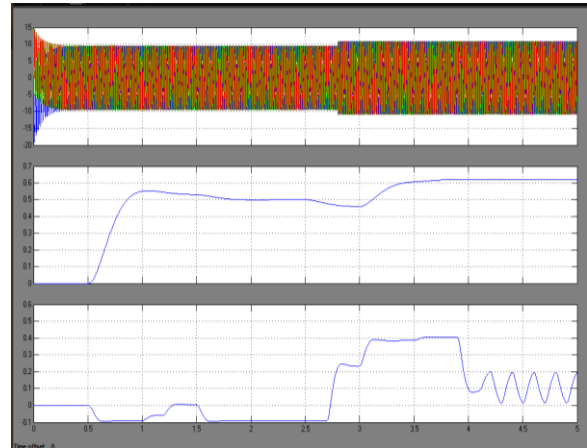
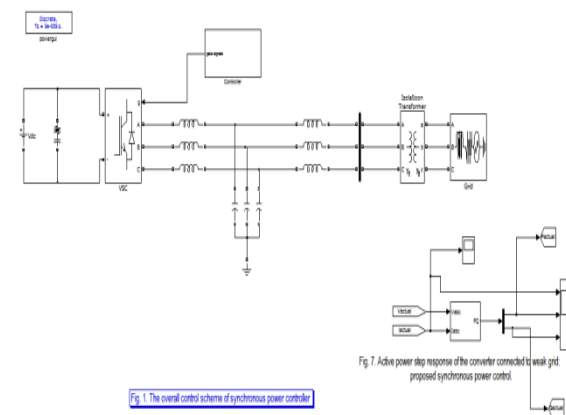


Fig.10. Active power step response of the converter connected to weak grid: The extension synchronous power control. b) Active Power c) Reactive Power

CASE-II

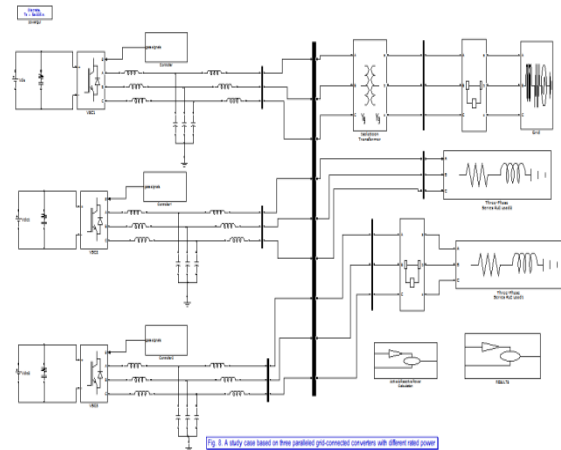


Fig. 11. The islanding action and load variations of a three-port system.

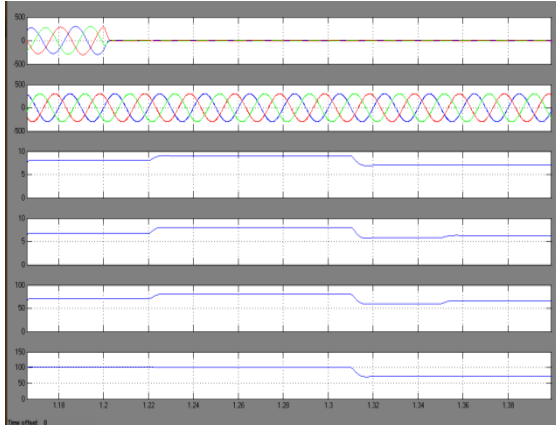


Fig. 12. The islanding action and load variations of a three-port system. a) Grid Voltage b) Load Voltages c) Converter1 active Power d) Converter2 active power e) Converter3 active Power f) Load active Power

Comparison table of proposed and extension

	Proposed	Extension
Case -I	43.64%	42.64%
I_{actual}		
Case -II	2.45%	1.30%
V_{grid}		
V_{load}	1.24%	0.48%

CONCLUSIONS

This paper proposed a synchronous power controller with inertia, damping and flexible droop characteristics for grid-connected power converters. The proposed controller shows more flexibility compared with the existing inertia emulation techniques, since it avoids the constraint between the damping and droop characteristics in the power regulating loop. Therefore, an outer P - f droop controller accompanied by a dedicated PLL is not needed for any operation phase, and the trade-off in designing the bandwidth of the

droop loop low-pass filter is avoided. Besides, the fixed power control can be easily achieved in spite of grid frequency variations.

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