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Fuzzy Logic based Synchronous Power Controller with Flexible Droop Characteristics for Solar PV Systems

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***Abstract:** In this project presents the expanding part of renewable power generation systems is a examining issue for the control and operation of the electrical systems. One of the principle issues is their absence of idleness, which is around into a more arresting issue as much as the share of the power plants in view of acceptable synchronous generators gets decreased. In such manner the new system codes request that these plants give new functionalities, for example, the frequency support and inactivity imitating.*

In this venture, 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.

***Keywords:** Renewable Energy Sources (RES), Synchronous Generator (SG), PLL.*

I. INTRODUCTION

Conventional generation plants in stand on renewable energy sources (RES) go about as network catering systems, which transport the greatest power from the capital source to the grid. As much as the diffusion of the RES generation plants amplify, the bankrupt latency in the entire system could attenuate its working correctness. Hence, the control targets and flow of the system connected converters should be drooped in accordance with take more burden in grid supporting issues, for example, dormancy copying, frequency direction and voltage regulation. The droop control action has been materialized in the control of grid connected converters. Despite the fact that the outermost 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 disability, which can't be bolstered up by load control without risking the steady operation of a grid connected converter.

A clarification for enhance the flow of the converters is to mark the inheritance 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 prevalent 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.

This project proposes a synchronous power controller with inertia, damping and flexible droop characteristics connected converters. Contradict and the current systems, damping and droop aspect are especially aim to, while the idleness highlight is kept up. The damping decapitation is critical for the convenient solidness and flow of the RES based generation systems. Besides, the droop aspect are important to amuse the required frequency support. Along these lines, reasonably than tuning an isolated framework to locate a becoming accommodation between both damping and droop qualities, a power circle controller is proposed to design damping and droop aspects independently. Also, an explicit connection among the controller gain, latency, damping associative and droop slope is given, and in this way the proposed strategy makes an adjustable control worldview conceivable in which the controller increases can be adaptive.

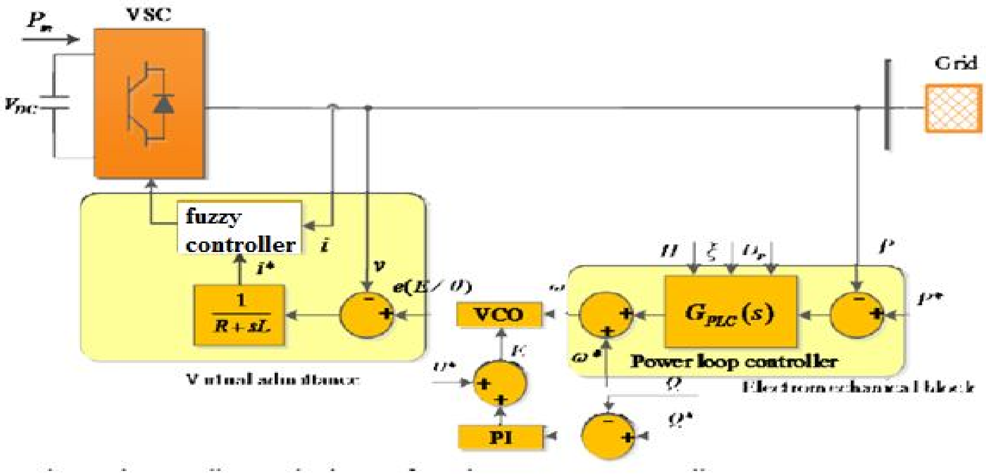

Fig.1. Control scheme of synchronous power controller.

II. OVERALL CONTROL STRUCTURE.

The proposed power loop controller is based on the general synchronous power control (SPC) building shown in Fig. 1. This control scheme is mainly described by two blocks, the electromechanical block and the virtual admittance block, which are as a result described. In addition to the control design shown in Fig. 1, outer loops can be combined. Depending on the demand of the grid and the composition and control action at the dc side, the outer loops can displace. Commonly a Q-V droop controller is added for delicate grid support and island grid building, And allowing the limited power reserve from the dc side, an outer

P-Vdc droop control can also be admit as an addition to the P-f characteristics.

Based on the customary control structure, the inertia can be actually integrated in the electromechanical control loop by consequence designing the power loop controller.

As shown in Fig.1, the power loop controller generates a basic synchronous frequency ω, which is then unified to a phase signal θ. combining the phase signal θ and the magnitude signal E (generated by the reactive power controller), the virtual electromotive force e will be generated by the Voltage Controlled Oscillator (VCO). In this case a PI controller is achieved in the reactive power control loop.

The virtual admittance structure adapt is selected as the structure of the inner control loops. It is an simulation of the output impedance of SG. This block plays a key role in load allocation and presents natural voltage magnitude droop affection for grid voltage support.

Compared with the well-known virtual impedance structure, the virtual admittance structure challenges the output impedance without leading to the arduousness in implementation. The main advantages lay on the effectiveness for the complete range of harmonic frequencies and the simplicity in the inner loop implementation.

According to the electrical characteristics of the synchronous machines, the generated active power can be approach to (1), considering that the output impedance of SG is mainly inductive.

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

Where ΔP is the additional generated power and **Δδ** is the incremental phase-angle difference between the virtual electro-motive force ***e*** and the grid voltage ***v*** in each phase. The admittance gain is expressed as,

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

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 modelled 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 registered 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. Reckless of the possibility that the network voltage edge θ fretwork 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

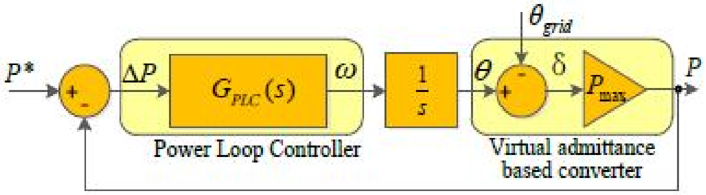

Fig. 3. Modeling of active power control loop converter.

As the axiomatic 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 brand parameters and the control parameters is exposed.

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.

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

In (3), P_{mech} is the information mechanical power, P_{elec} the output electrical power, ωs the synchronous crossing frequency, J the crack of inactivity and D the damping parameter. Despite the fact that the damper squirm of SG can give the damping impact, it is moderately restricted. Considering this reality, the damping of the power circle can be encircled 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 attributed as mechanical power circle (MPL) controller in this paper.

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

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

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

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

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

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

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

Rather than utilizing the crack of idleness J to assign the latency aspect, the inactivity consistent H is regularly accepted, which is characterized in (6), which means the time it takes to accelerate the rotational speed from zero to ωs utilizing full power SN.

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

For analysing the dynamics of the power control circle, the reaction to frequency agitating 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 ωg as the variable while taking P as the capacity, the connected transfer function (P-f response) is shown in (7).

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

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

$$D_p = \left(\frac{2\pi}{1000}\right) \cdot \left|\frac{\Delta P}{\Delta \omega_g}(0)\right| \frac{kW}{hz} \qquad (8)$$

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

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

It is seen that the MPL controller realizes a constant power synchronizing conduct the length of the fretwork 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 another demonstrate the limitations of the MPL controller in parameters tuning, the matrix frequency aberration rate that concentrates the full evaluated control from the converter is utilized as the marker of the hang aspect, which is spoken to by 1/R. The connection amongst DP and 1/R is appeared in (10)

$$\frac{1}{R} = \frac{2\pi S_N}{D_p \omega_g} \qquad (10)$$

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

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

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

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

Equation (11) shows the communication among H, ξ, Xpu 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 condition between ξ and 1/R.

This condition is anticipated , where H is specified to 2, 11 and 20 respectively in three cases. The grid nominal frequency is set to 50 Hz and Xpu is set to 0.3 to specify the model.

Once the damping coefficient ξ is tuned and fixed, the attach incline will be settled, as well. However then again, the attach incline should be indicated considering the frequency variety of the utility fretwork and the power save of the era plants. For conventional synchronous generators, a commonplace scope of attach 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 achievable. In the bearings appeared in Fig. 4, 1/R is underneath 3%. On the off chance that 1/R is required to be more arresting, ξ must be attenuate, which undermines the damping execution.

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

IV. CONTROL PARAMETERS SETTING

The control parameters KP, KI and KG can be apparently set by the contribution of DP, H and ξ. consistent from the express connection between the controller additions and identification parameters, the controller can without much of a expansion be made accomplished as per the auxiliary control, and an adaptable control worldview gets to be sharply 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 collection 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. Additionally, the damping coefficient ξ can be set considering the normal apprise range to make a steady and under-damped framework. 10<<ξ

So as to further tune ξ, the investigation on progression is done in view of the scientific move capacities given in the previous area. Exhaustive stride information is given to the shut circle switch work (14a), and the impact of ξ on the arranging time and overshoot of the time reaction can be determine. At that point ξ can be accommodated to meet the necessities of the converter and the network. The investigation on the connection amongst ξ and the overshoot of the progression reaction is appeared in Fig. 4. Since the overshoot of the progression reaction can impressively mirror the damping attributes of the framework, esteem more noteworthy than 0.7 is proposed as the best possible damping esteem, which can ensure the overshoot of the progression reaction to be littler than 25%.

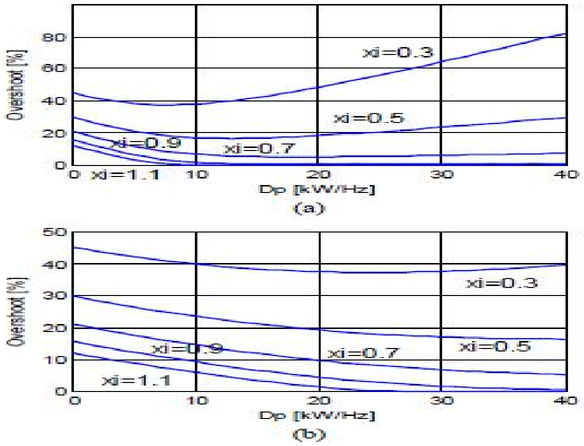

Fig.4. The influence of the damping coefficient ξ on the overshoot of power step response: (a) H=2 and (b) H=20.

V. SIMULATION RESULTS

Simulation analyses are conducted for measuring the performance of the advanced controller in case of grid connected converter connecting weak(high-impedance) grid and island operation.

A. Existing system simulation.

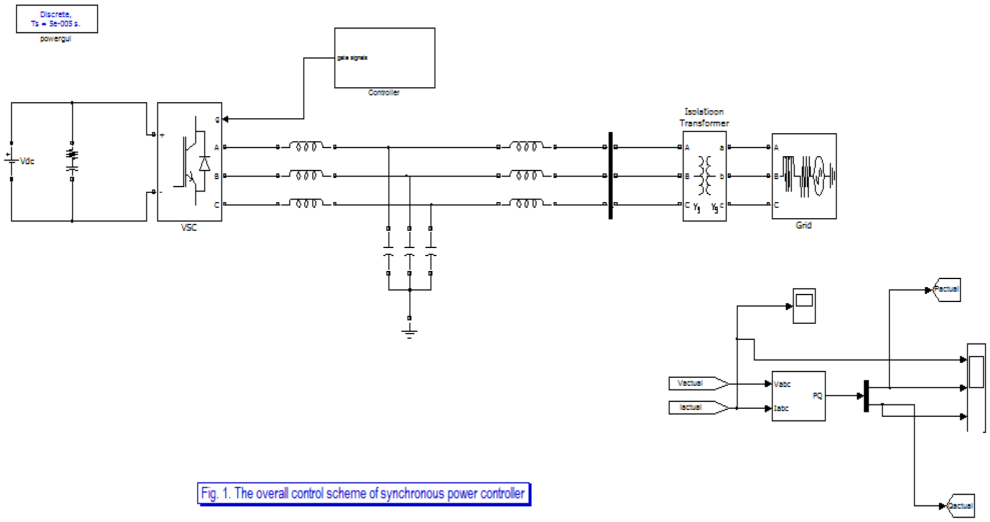

Fig.6.Simulation of synchronous power controller.

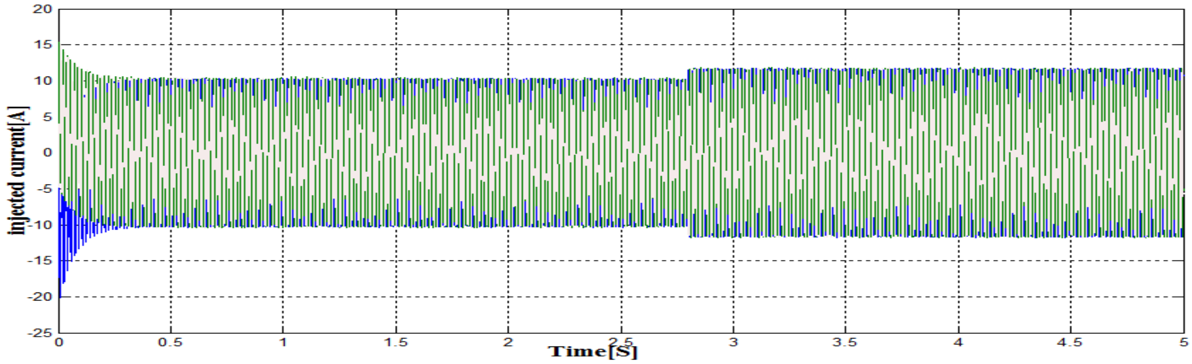

Fig.7.Injected Current.

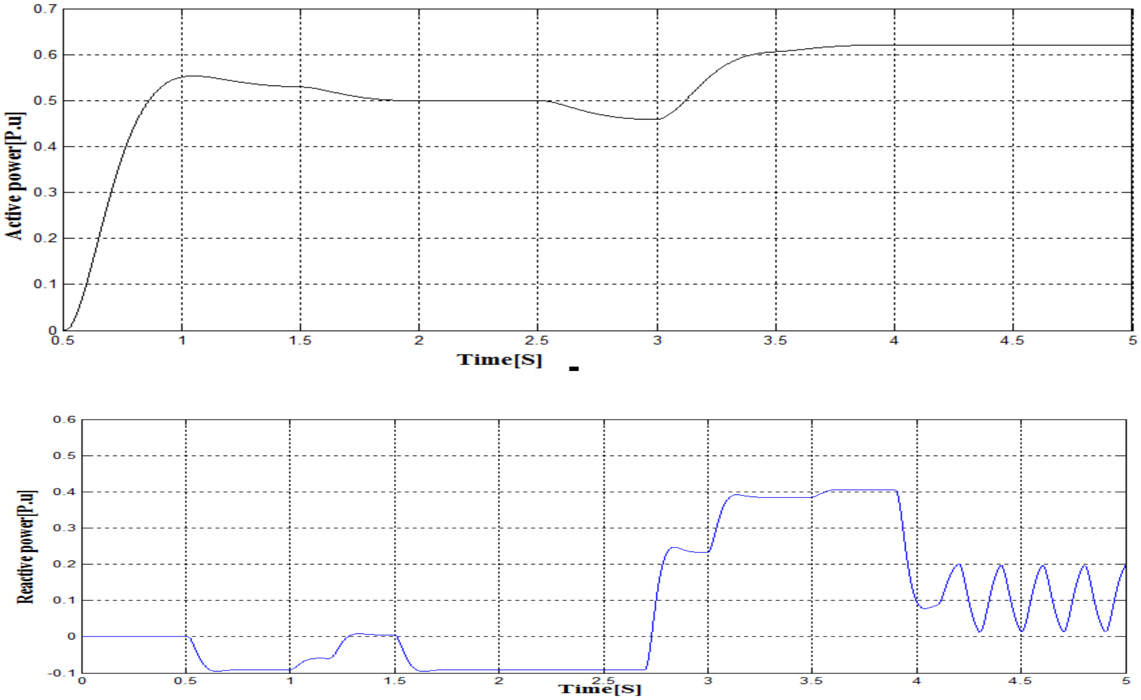

Fig.8.Step response of the converter connected to weak grid Active and Reactive power.

B. Performance of grid Connected Converter Connecting to Island Operation.

1) Case. II

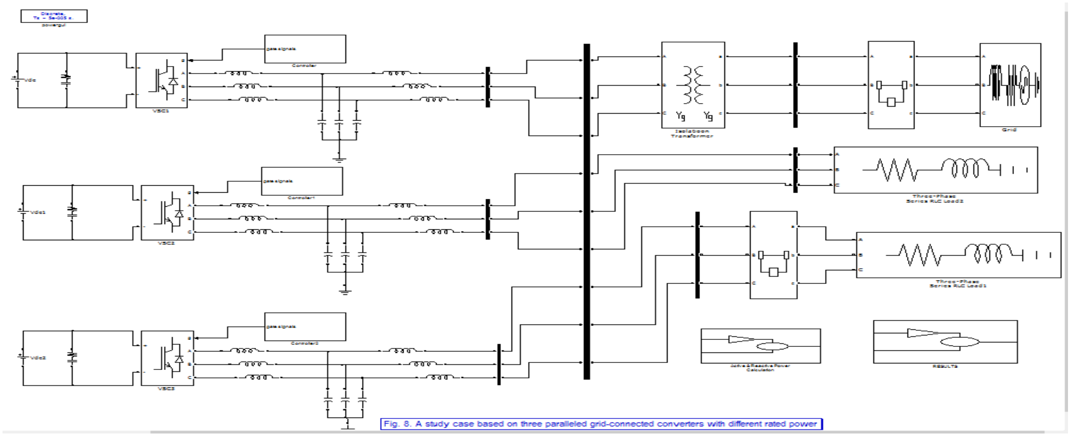

Fig.9.Load Variations of a three port system.

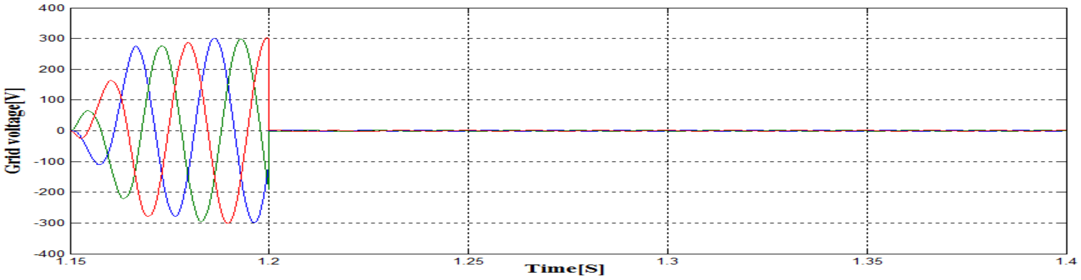

Fig.10.Grid voltage.

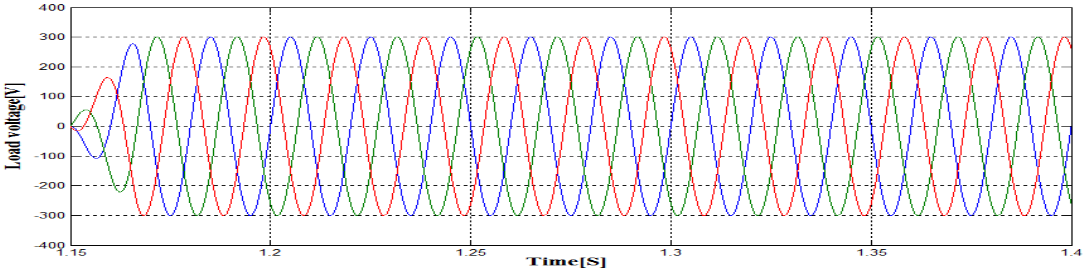

Fig.11.Load voltage.

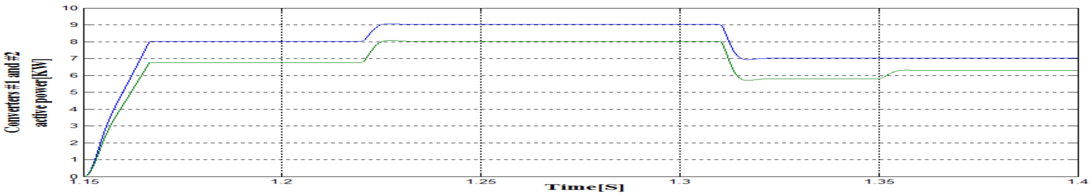

Fig.12. Converter #1 and #2 active power.

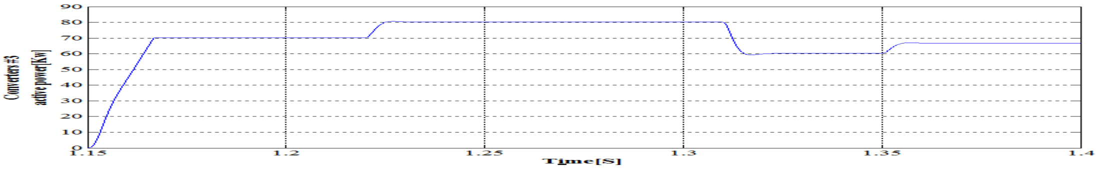

Fig.13.Converter #3 active power.

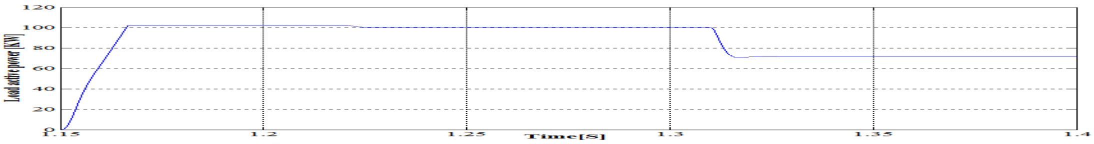

Fig.14.Load active power.

2) *Fuzzy logic controller:* It was introduced by Dr. Lotfi Zadeh of professor at the University of califormia at Berkiey in the 1960's as a means to model the lack of confidence of natural language. He says that fairly than regarding fuzzy theory as a single theory , we should regard the process of "fuzzification" as methodology to hypothesized any specific theory from a crisp to a continuous form. Thus recently investigators have also introduced "fuzzy calculus", "fuzzy differential equation". Performance of traditional control "PI", its response is not satisfied for non-linear systems. The betterment is arresting when controls with Fuzzy logic are used, obtaining a better dynamic reaction from the system.

The PI controller requires precise linear mathematical models, which are difficult to obtain and may not give satisfactory performance under parameter variations, load disturbances, etc. Recently, Fuzzy Logic Controllers (FLCs) have been introduced in various applications and have been used in the power electronics field. The advantages of fuzzy logic controllers over conventional PI controllers are that they do not need an accurate mathematical model work with imprecise inputs and can handle non-linearity and more robust than conventional PI controllers.

Fuzzy logic controller is an advanced controller. It is control both frequency and inertia. Fuzzy logic controller reduces harmonics in grid connected converter. By using fuzzy logic controller injected current will be decreased. fuzzy logic controller characterized by both damping and droop characteristics are particularly addressed, while the inertia feature is maintained. The damping performance is important for the local stability and dynamics of the RES based generation systems. Power converters are economically satisfied by using fuzzy logic controller.

C. performance when interfacing Weak Grid:

1) Case. I

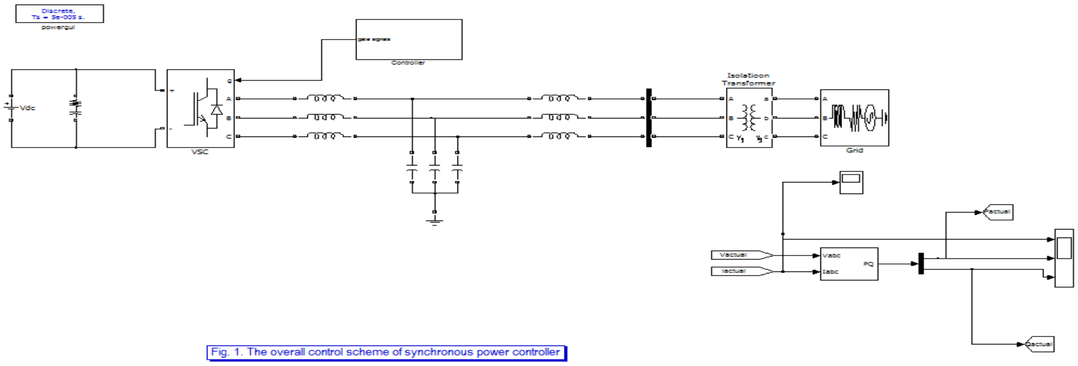

Fig.15.Simulation of synchronous power controller.

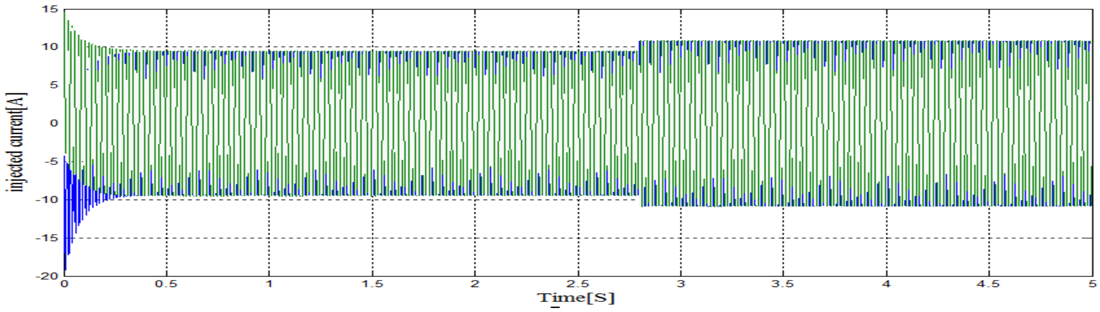

Fig.16. Injected Current.

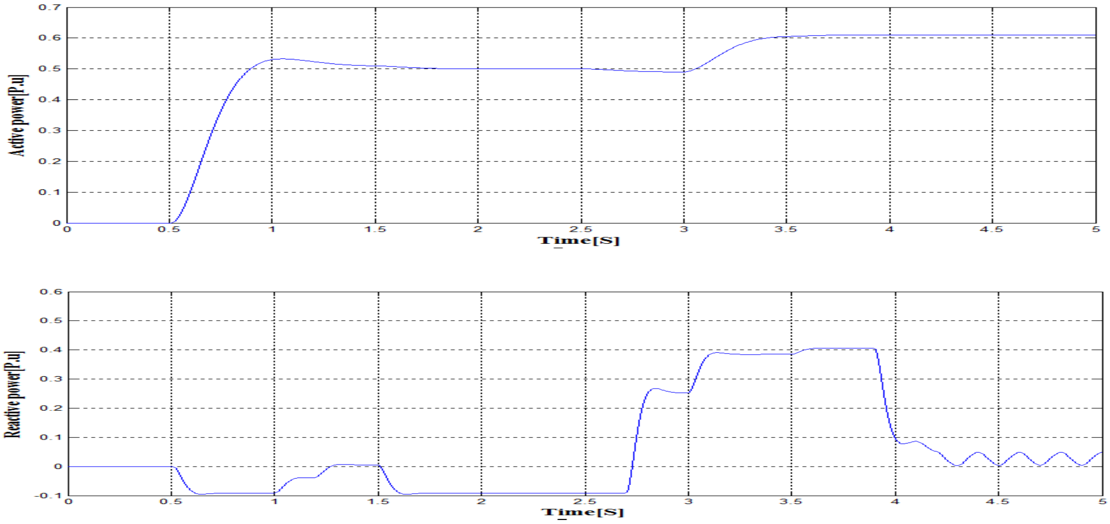

Fig.17.Step response of the converter connected to weak grid Active and Reactive power.

D. Performance of grid connected converter connecting to island operation

1) Case. II

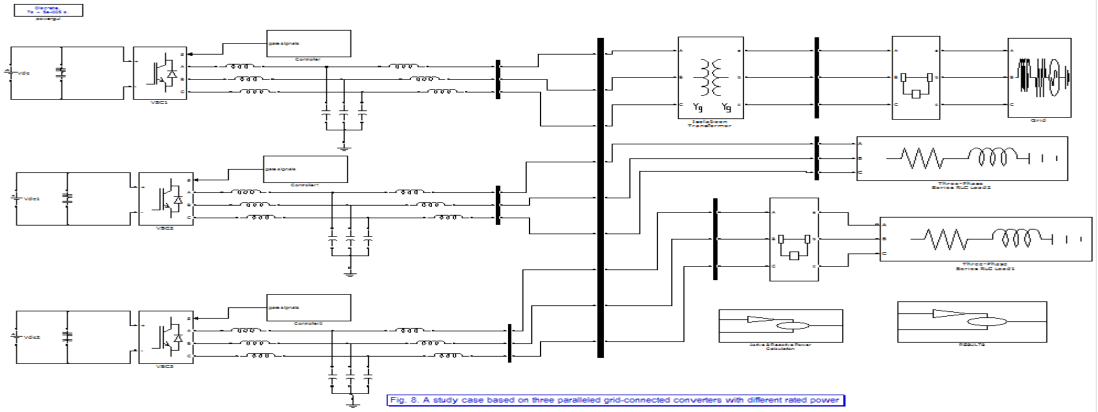

Fig.18.Load variations of a three-port system

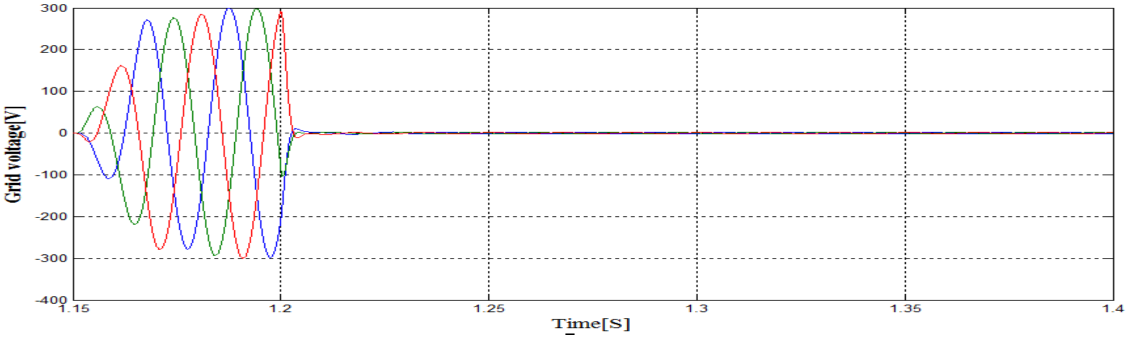

Fig.19. Grid Voltage.

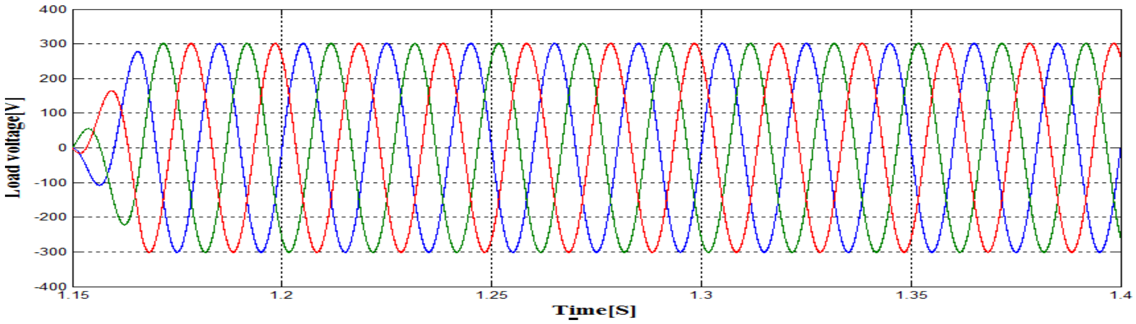

Fig.20. Load Voltages.

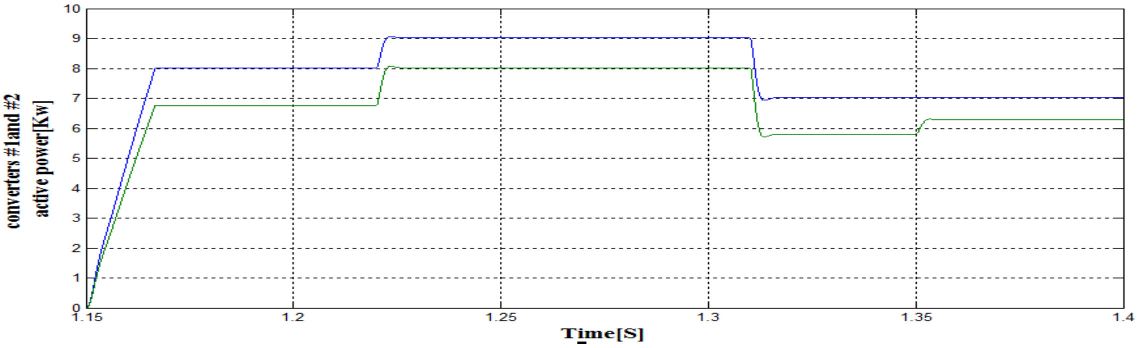

Fig.21.Converters #1 and #2 active power.

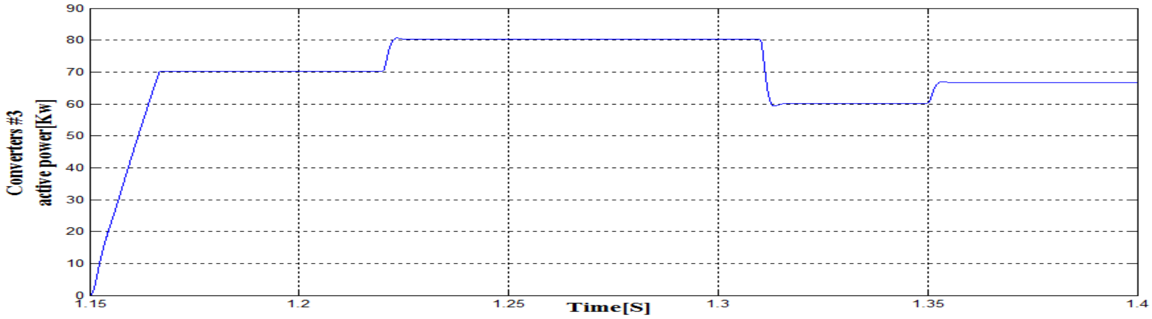

Fig.22.Converters #3 active power

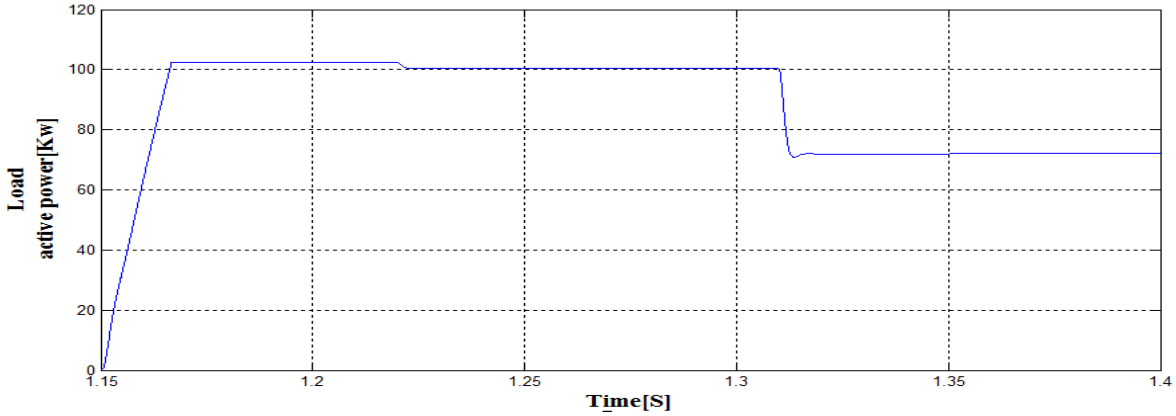

Fig.23. Load active Power.

VI. CONCLUSION

This work 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 stage, 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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