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Performance Enhancement of Load Frequency Control of Microgrid using Ant Colony Optimisation

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***Abstract*—Rapid increase in renewable energy penetration to grid brings down the inertia in the system which leads to wide fluctuation in frequency during load change or other system disturbances. An efficient control algorithm is required to mimic the inertial behaviour of a conventional synchronous machine during transient conditions by means of fast-responding external energy reserve. A Virtual Synchronous Machine (VSM) and an inverter model is also discussed to integrate the Energy Storage System (ESS) to the grid. A Double Second-Order Generalized Integrator Phase Locked Loop (DSOGI-PLL) is also discussed which is capable of synchronizing the system under distorted and unbalanced situation. For this proposed work an ant colony optimization technique is used for the controller design.**

***Index Terms*—Virtual Synchronous Machines (VSM), Energy Storage System (ESS), Frequency regulation, Double Second Order Generalised Phase Locked Loop, Renewable Energy Integration, Ant Colony Optimisation and Primary Frequency Regulation.**

I. INTRODUCTION

A. General Background

The advanced technology incorporating the RESs is specifically termed as distributed generation (DG) that greatly helps in reducing the dependency of mankind into fossil fuel consumption. This advancement of power mode took many years to transform and upgrade to the way we use it now and would considerably take time to implement the ideologies thar arise in the field of power systems from various researchers.

The synchronous generator has been the backbone of the power system overtime, since its creation for simultaneously providing energy and ancillary services. When considering the inclusion of renewable energy sources into grid there are also many constraints that would arise for proper functioning of the system of which primarily arising constraints would be the system frequency and voltage control. A variety of such techniques have been encountered during literature survey which will be discussed in later chapters. The generation of virtual inertia in place of SM has been attainable due to various ideologies and its successful implementations. Along with the introduction of VSM there is a need to typically control the overall system working especially during transients. Such innovative technologies will undergo several updating processes of which the end results would bring out such fruitful strategies at a more advanced level.

II. LITERATURE REVIEW

The inclusion of RES into conventional system thereby which with allocation of proper technology the operation of conventional power system has been able to be redefined by a far extent. In [1] it introduces an innovative

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derivative technique basically developed on the basis of two area AGC system. A variety technique in overviewed in [9] where it deals with a VSC-HVDC based control network. In [2] it provides a brief idea regarding the modelling of synchronous generator.
When considering a microgrid control with the concept of VSM in [11] it is overviewed that in order to stabilize the grid frequency, they discuss about adding an implied rotational inertia to DGs. Another approach in VSM is discussed in [12] where it employs a VSM-based control. In [3] it discusses about variables related to frequency compensation capability of WT. Another conceptual viewpoint of VSM is discussed in [13] about the habitual contours imparted by the VSM concept, also in [14] it deals with a virtual inertia control mechanism along-with a bi-directional grid-connected converter (BGCs). In [4] it highlights a hybrid ESS including a battery and ultracapacitor. Another strategy regarding ESS is seen in [15], it focuses mainly on the foremost regulation plan that deals on yielding oversight theory. whereas in [16] it suggests an unbending frontal generalised technique and in [18] it focusses a distributed finite-time control approach along with a distributed frequency control, whereas in [19] it elaborates about a parted frequency and voltage governor for DGs, and in [20] they provide a coordinated control strategy along with a BSM method. In [5] it gives an active power control solution for Grid interactive converters. Furtherly on [6] it focuses to increase inertia of PV system. Alternatively, on [7] it introduces a derivative technique which is developed for two area AGC system. In [17] perceives a methodical approach for monitoring an ESS. Also considering [8] it provides a modified VSM control strategy based on swing equation. Also, an advanced strategy is foreseen in [10] where it discusses about a frequency regulation scheme (FRS}. So, with the attained results to make it more effective and efficient proper advanced optimisation techniques is performed.

III. METHODOLOGY

On accounting to various techniques related to grid control or stabilisation precisely here we look onto the frequency control as the main function as per in accordance to load change which ultimately leads to system stabilisation. Different controlling methodologies have been encountered during literature for the system stabilisation having being the main aim. The basic methodology highlighted in the discussion has the basic operation as shown in the fig.1 below:
In the specific methodological block diagram shown here it holds good for the desired aim. It includes an inverter to which it has two connections namely the VSM and the ESS external storage system. The functionality of this ideology works such that the output of inverter is filtered using specific filtering components and is given to load that is connected to grid also. A typical feedback mechanism that includes a DSOGI-PLL along with a decoupled current control strategy is employed here that detects the variations encountered in the load system which ultimately affects the system frequency and this feedback system provides suitable control mechanism namely VSM which in turn keeps the system frequency stabilised thereby which the whole system could be maintained in a stable manner.
In many of the microgrid stabilisation control technique the terminologies that arise in terms of controlling strategy would be voltage and frequency control where the former is achieved by reactive parameter and the latter aspect which is specifically discussed here is achieved by the active power injection in the system during

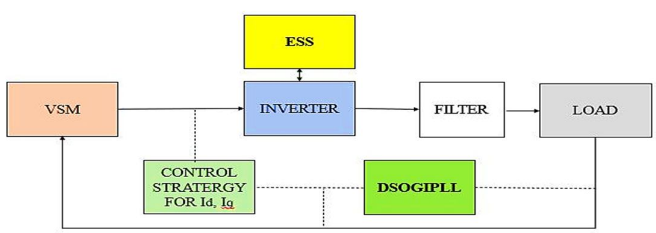


Fig.1 Basic Methodology

the event of load variation. In both the cases of load variations all the control strategies have their major part denoting its working will be based on how effective the system feedback mechanism is developed and how much sensitive and reliable it would be, or else the corresponding feedback mechanism would not hold good for the desired operation. So, always the strategy regarding in each system should be dealt with prime concern. And in this specific strategy it employs advanced mode of feedback mechanisms along with certain steps of control strategies. Here it employs a much more advanced feedback mechanism as said earlier which is more efficient than the conventional phase locked loop typically termed as PLL.

In most of the systems reviewed the main feedback relies on the PLL, but the PLL itself has its own dynamics and would create a small-time lag in terms of operation for system stability during load disturbances, so as remedy to this the feedback employed in this discussion would be a double second order generalized PLL termed as DSOGI-PLL that employs two sets of single order generalized phase locked loop which on computation would produce the angular velocity and the theta value which are further required as inputs for effective working of the decoupled current control. Along with the feedback this strategy it also employs a decoupled current control operation for effective working of the system and to stabilize the system during load variations. The further explanation regarding the feedback and the control strategy would be evidently seen in later sections. The feedback system employed here also has an advantage that it becomes functional only when there is a change in load thereby frequency which triggers the switches in the inverter by proper gating pulses and this triggering helps to build up the load required in order to maintain the system frequency. The basic functionality of the system during an event of load change would be that the active power injection from ESS tends to decrease and from that of VSM increases and when the system attains stability the ESS output would be zero and the total power would be delivered by VSM mechanism.

The basic functioning of this specific ideology is as said above and typically it holds good for the required operation and fundamentally for the filtering process here an RC and RL components are employed and the load considered here is an RL load. Consideration of the parameter values for this work is attained by trial-and-error method and the more detailed view of the controlling strategies, and feedback mechanisms employed in this specific work is discussed in the later sections which in turn will provide a more realistic aspect regarding the microgrid stabilisation achieved through the phenomenon of frequency control.

IV. Tools In Methodology

The basic schematic diagram of the overall developed system is shown in fig.2 below.

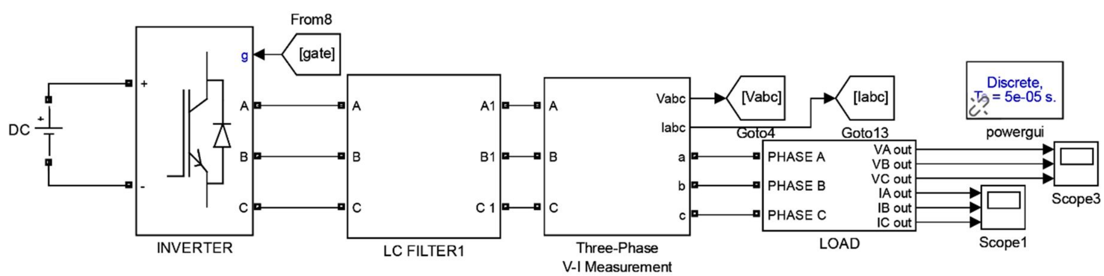


Fig.2 Developed overall system

The tools mainly employed in this discussion regarding software is MATLAB and that for the controlling procedure are as given in the following sub-chapters.

A. VSM

The VSM technique includes basic controlling of voltage or frequency as per function defined, here frequency regulation according to load variation is the prime motive. The working of VSM is explained as the combined and effective working of a DSPGI-PLL mechanism along with a decoupled current control strategy that plays the role of effective VSM namely Virtual Synchronous Machine. This concept of frequency control holds good for load variations occurring in the system. This strategy as mentioned only becomes active or effective during the event of load change. In the system initially it works on the source and ESS, and during the inclusion of load change the VSM strategy begins to trigger and gradually takes up the load and this goes on till the system attains the prime aim of frequency stabilization.

B. ESS

The ESS, external storage system is always linked to the inverter terminals for continuous supply of energy into the system by the inclusion of RES, renewable energy sources. During the inclusion of renewable energy concept many constraints also has been raised of which the most important being the system stability during the event of interconnection of DGs to grid. In this discussion the ESS is analogised and given as a DC source. Since the terminal introduction of ESS into the field of microgrids several techniques have been dealt with highlighting the importance of each ESS employed techniques encountered in the literature.

C. Inverter

The main operation of inverters is the transformation of voltage from DC to AC. On incorporating the DGs into the power system the operation of inverter plays a vital role in the transformation process in order to power the load connected.

In this discussion the ESS is directly linked to the inverter which is furtherly filtered and given to load thereby grid. The gate triggering pulses given to the inverter is achieved by the VSM strategy that involves a decoupled current controller along with a feedback DSOGI-PLL which is deeply explained in subsections.

D. Filter Circuit

Filter circuits are mainly employed to eradicate the discontinuity that arise from any signal and convert them into smooth signals of the desired type. In this discussion the filter circuits employed are RL and RC components, through which the inverter output waveforms are smoothened and the required smoothened ac sinusoidal waveforms are achieved. The values of the filter components are designed using generalised formulas employed for filtering operation. In this filter subsystem suitable scoping is performed to verify the filtered output, attained voltage sequence along with current waveform attained.

E. Load

All the strategies leading to advancement in technology is basically for operating of system under loaded condition and to attain effective working in the same load when considering sources like renewable energy sources and DGs. In this discussion the main motive is to maintain the frequency under load variations by properly injecting active power into the system with respect to load change and for this operation effective mechanism including DSOGI-PLL and decoupled current controller is employed. The load considered in this specific discussion is a RL load that is interconnected to the grid and all the analysis and experiments are performed in this system to verify the frequency stabilisation concept according to load change with the usage of above said advanced techniques.

F .Decoupled Current Control

The advanced controlling strategy employed in this discussion is the decoupled current control where it effectively controls the input signals entering to it and helps in generation of required PWM signal which on further conditioning gives the required firing signals for gate terminals of the inverter so that fast and effective operation can be carried out during the event of load change and corresponding it helps the system to maintain its nominal frequency during such events and this particular controller only becomes effective during the event of load change, the internal diagram of this controller is shown in fig.3 below. This figure also shows how this block actually performs its operation leading to generation of desired PWM signals for the triggering purpose.

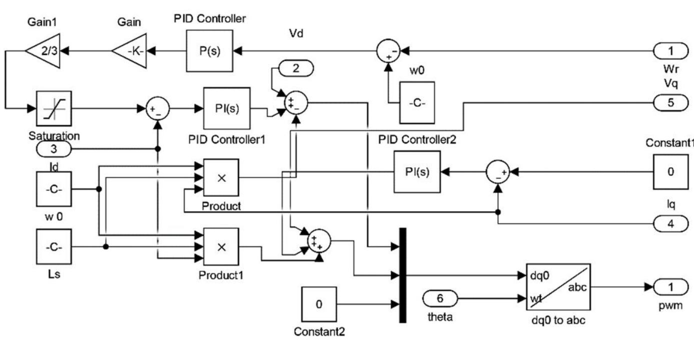


Fig.3 Decoupled current control

G. Feedback Mechanism

Any system needs an effective feedback mechanism in order to perform in the most efficient manner. The reliability and effectiveness of the system is attained high only when the feedback mechanism employed holds good during its operation. Considering DGs, or conventional power generation systems the normally used feedback mechanism was PLL, but the PLL employed itself has its own dynamics which makes it a bit slower for its effective operation to carry out at the required action time, this slowness is pace also affects the fast stabilisation action of the system during the event of load change, so in this particular discussion instead of PLL an advanced strategy is employed which holds good for the event of load variation and provide quick action response in order for the system to maintain stability at a fare more pace than conventionally used PLL. The deep explanation of the feedback mechanism of DSOGI-PLL which is shown in fig.4 below.

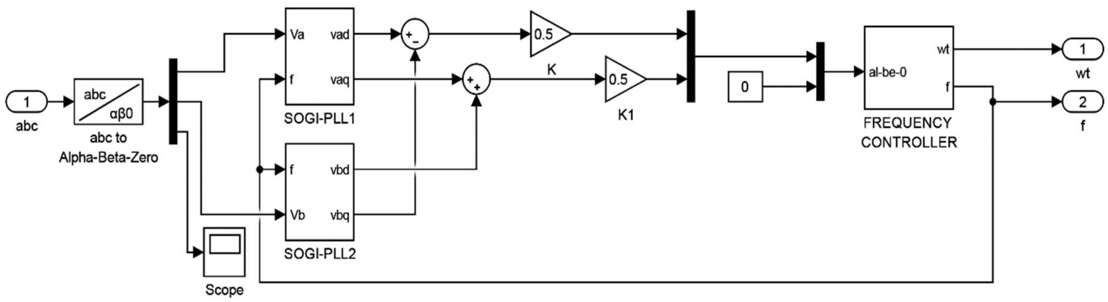


Fig.4 DSOGI-PLL control system

In the feedback mechanism employed here it considers the voltage and its corresponding current values where it is transformed in order to attain required signals. The basic feedback mechanism employed where both voltage and current signals are transformed into dq0 components from abc in order to attain V_d, V_q and I_d, I_q respectively, this mechanism also employs a frequency controlling strategy as evident from the block diagram below which holds good for entire system operation for the event of load change and as a result of load change these mechanism helps the system to gain back its stability at a great pace.

H. Ant colony optimisation

The performance of the system can furtherly be improved by incorporating an optimization technique like the ant colony algorithm by which artificial ants are employed to find best solutions for the desired objective function basically achieved in three steps:

1.Initially the objective function is identified.

2.The pheromone values are analysed.

3.The attained values are updated in terms of iteration, and finally the values get converged to a particular value which will be the best solution for the desired objective function. In this discussion the objective function is set to get the minimized value of the sum of peak-overshoot and settling time as shown below:

$$z = minimize F(x) \tag{1}$$

$$x = \Sigma(T_S, m_p) \tag{2}$$

where T_S=settling time, and m_p= peak overshoot.

The settling time is the time for the system to become stable during load change and peak overshoot occurs when system encounters load variation. This particular objective function helps in attaining the controller values, i.e., the controller values are attained for minimum value of the objective function.

V. RESULTS AND ANALYSIS

For the experimental validation the parameter values used in this discussion is given in the table1 below and the output waveforms obtained are analysed. The filtered voltage and load voltage obtained in voltage-time and current-time axis are shown in fig.5 and 6 respectively.

TABLE I. SYSTEM PARAMETERS

Parameters	Value
Nominal frequency	50Hz
L_s, L_g	0.45mH
R_s, R_g	0.135Ω
C_1, C_2, C_3	22µF
DC link voltage	100V
P gain of Decoupled current control	Kp=7
PI gain of d-axis controller	Kp_1=12, Ki_1=26
PI gain of q-axis controller	Kp_2=12, Ki_2=26
PI gain of frequency controller	Kp=0.948, Ki=3.92

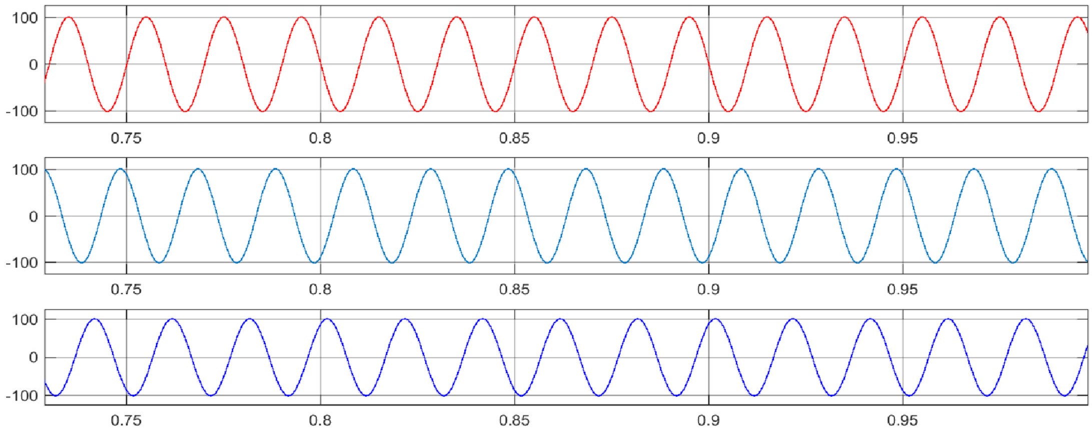


Fig.5 Filtered voltage

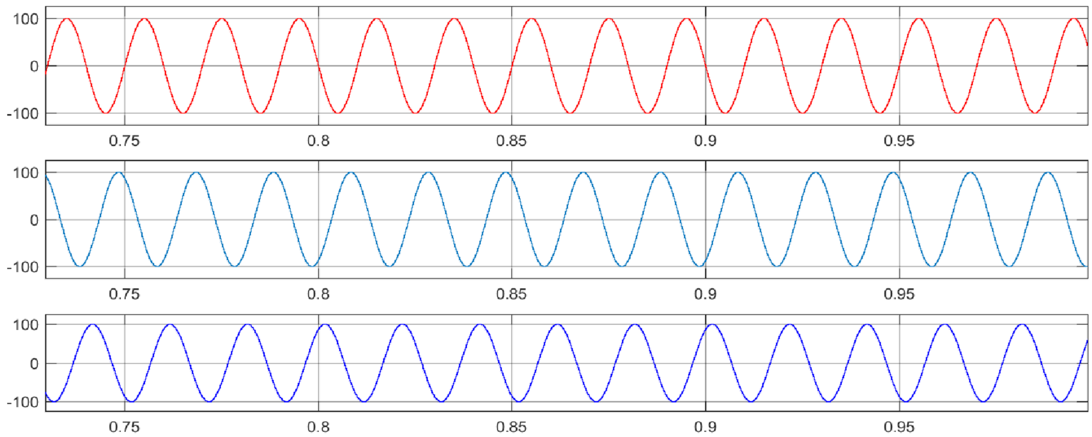


Fig.6 Load voltage

Similarly, the obtained frequency response waveform of the system obtained in frequency-time axis is shown in fig.7 and in order to validate the controller parameter values as discussed ant colony optimization technique is executed as an algorithm by defining an objective function and by iterations the controller parameters are attained, and the waveforms obtained that depicts the objective function, proportional and integral value of the frequency controller are displayed on fig.8,9 and 10 respectively.

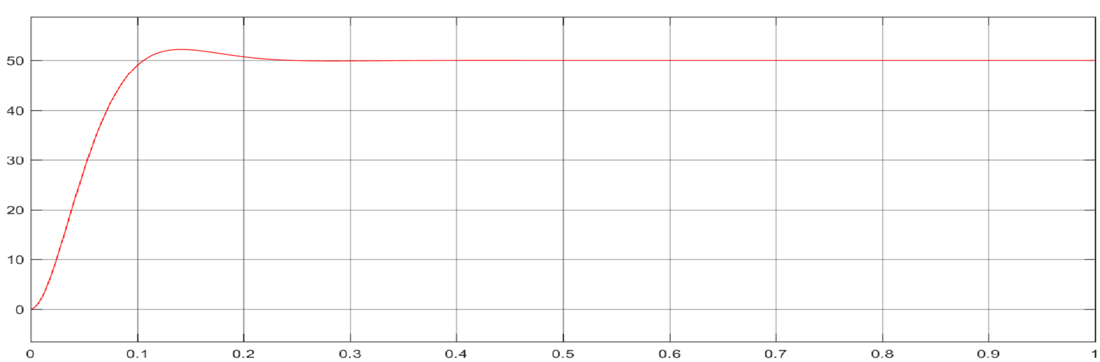


Fig.7 Frequency response

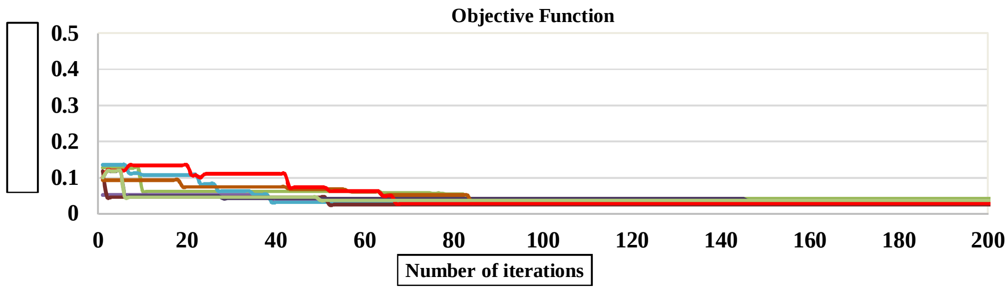
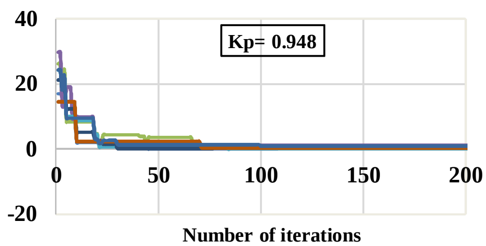


Fig.8 Objective function



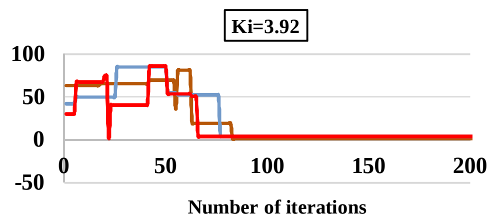
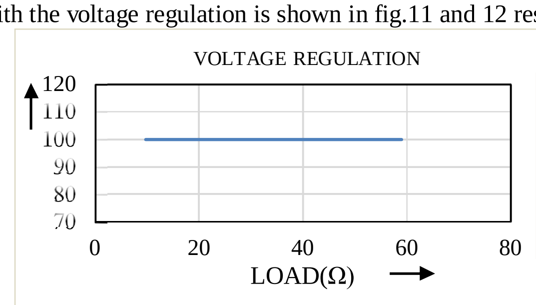


Fig.9 Proportional gain value

Fig.10 Integral gain value

In order to strictly confirm the effectiveness of the control strategy used the frequency regulation curve along with the voltage regulation is shown in fig.11 and 12 respectively.



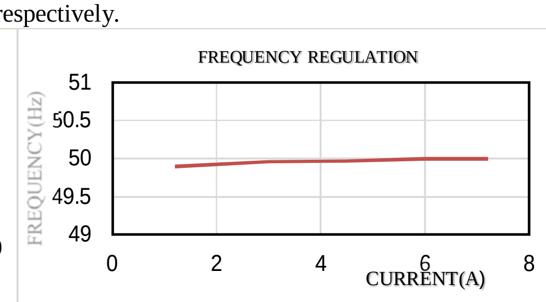


Fig.11 Voltage regulation

Fig.12 Frequency regulation

The simulation results displayed in this section effectively shows the performance of the system during the event of the load change with the inclusion of ant colony optimization technique to identify the best controller parameters for effective working.

VI. CONCLUSIONS AND FUTURE SCOPE

As technology advances there is a need to update the techniques used in power generation and distribution and on coming years RES would play a great role and in order to incorporate these renewable DG sources the overall system needs to be updated. Various updating techniques have been discussed here of which a particular strategy has been experimented in this particular discussion. The frequency regulation strategy employed here holds good for the required operation which is evident from the frequency regulation curve, also the controller parameter values obtained from the ant colony optimization algorithm are optimum without which frequency regulation with respect to load variation and the voltage regulation could not be achieved. The obtained results can be bettered if more advanced optimizing techniques can be employed into the system as of which a more better frequency response profile could be achieved.

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