A Novel Voltage Unbalance Compensation Control Strategy for DG Interfaced Converters in an Islanded Microgrid

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Abstract: This paper focuses on islanded microgrids where the interfacing converters mainly operate as voltage sources to participate on the voltage and frequency regulation while sharing at the same time active and reactive power accurately by adjusting output voltage phase angles and amplitudes. However, it is also well known that those converters could provide power quality management ability especially for voltage/current unbalances and distortions in a microgrid in such a way that full use of these converters available capacity can be utilized. The negative sequence component of the common bus is hard to suppress, since the microgrid central controller (MGCC) uses the voltage unbalance factor as a main control variable, which value is reduced by the positive sequence voltage. In order to overcome these drawbacks, a control scheme located in the MGCC which directly acts over the negative sequence voltage is proposed in this project work. The proposed control strategy for paralleled three-phase inverters for an islanded microgrid achieves satisfactory voltage unbalance compensation. The effectiveness of the control scheme has been studied with PI and fuzzy based voltage unbalance compensator in an AC microgrid in the MATLAB/Simulink software.

KEYWORDS: Microgrids, voltage unbalance compensation, microgrid central controller (MGCC), point of common coupling (PCC)

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INTRODUCTION

In recent years, distributed energy resources (DERs), like wind turbines, electrical phenomenon systems and micro-turbines, have gain a good increasing interest since they're economic and surroundings friendly. In general, power electronic converters area unit used as interfaces between DERs and therefore the grid, specified electric power with smart quality and high responsibleness is delivered to the load or utility grid, as shown in fig. 1. This work focuses on islanded microgrids wherever the interfacing converters principally operate as voltage sources to participate on the voltage and frequency regulation whereas sharing at a similar time active and reactive power accurately by adjusting output voltage section angles and amplitudes. However, it is also preferred that those converters might give power quality management ability; in such the way that full use of the converters out their capability will be taken. it's accepted that power quality problems, particularly voltage/ current unbalances and voltage/current distortions became additional and additional serious in fashionable facility. for example, in islanded microgrids, the voltage unbalance drawback may be a salient issue principally made by the utilization of single-phase generators/loads and it will result in instability and power quality problems.

In order to reinforce the voltage wave quality, many elements to manage the voltage unbalance compensation are developed, like static volt-ampere compensator (STATCOM), series active power filter and shunt active power filter.

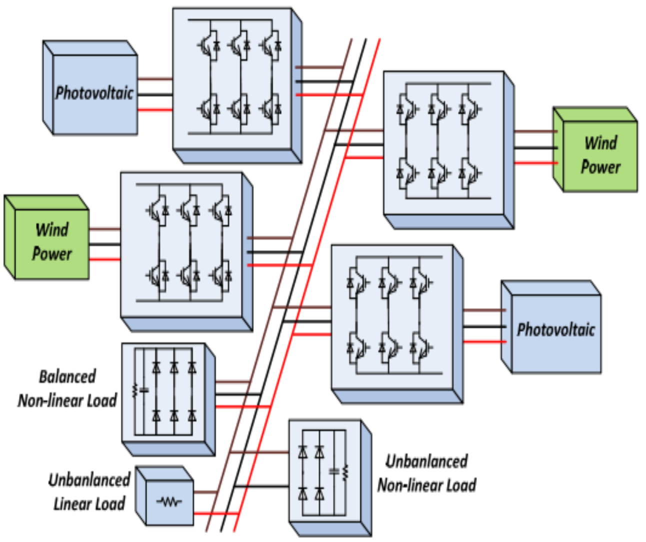

Figure 1: General architecture of a Microgrid

However, of these compensation strategies utilize extra power converters to inject negative sequence reactive power. solely many works compensate the unbalanced voltage by utilizing the DG interfacing converters. The DG electrical converter is controlled to inject negative sequence current to balance the common bus voltage. However, a surplus device capability is required to come up with the negative sequence current and also the injecting current may be too high underneath severe unbalance conditions. within the literature, Associate in Nursing unbalance compensation technique is planned by causation correct management signals to DGs native controllers. However, the negative sequence element of the common bus voltage is tough to suppress, since the microgrid central controller (MGCC) uses the voltage unbalance issue as a main control variable, that worth is reduced by the positive sequence voltage.

In order to beat these drawbacks, this project proposes a controlscheme settled within the MGCC that directly acts over the negative sequence voltage. The management style of native controllers, primarily as well as inner voltage/current loops, virtual impedance loop and droop controller employed in microgrid then the systemmodeling is introduced. presently investigate the strategy of the projected direct voltage unbalance compensator.

Structure of paper

The paper is organized as follows: In chapter1, the introduction of the paper is provided along with the structure, important terms, objectives and overall description. In chapter 2 we discuss literature survey. In chapter 3 we have the complete information about unbalance compensation for DG interfaced converters in islanded microgrids. Chapter 4 shares information about the design and implementation of the controllers. chapter 5 tells us about results and the process description. Chapter 6 tells us about the future scope and concludes the paper with acknowledgement and references.

LITERATURE SURVEY

There are numerous works that have been done related to power quality improvement like unbalance voltage, current compensations are given below

H. Nikkhajoei and R.H. Lasseter [1] are proposed on the energy storage system and the power electronic interface included in microsources of the CERTS microgrid. CERTS stand for the Consortium for Electric Reliability Technology Solutions. This necessitates attaching an energy storage module to some or all of the microsources. The storage module is attached to the prime mover through a power electronic interface that couples the micro source to the microgrid. Details of the energy storage module, the power electronic interface and the corresponding controls are described. Performance of an example micro source, which includes a synchronous generator, a storage module and an electronic interface, is studied.

Y. Xu, L.M. Tolbert, J. D. Kueck, and D.T. Rizy [2] proposed a three-phase insulated gate bipolar transistor (IGBT) based static var compensator (STATCOM) was used for voltage and/or current unbalance compensation. An instantaneous power theory was adopted for real-time calculation and control. Three control schemes - current control, voltage control and integrated control are proposed to compensate the unbalance of current, voltage or both. .

P. S. Flannery, G. Venkataramanan [3] proposed regulatory standards for grid interconnection require wind generators ride-through disturbances such as faults and support the grid during such events. Conventional accommodations for providing voltage sag ride-through for doubly fed induction generator (DFIG) wind turbines result in compromised control of the turbine shaft and grid current during unbalanced faults. This paper presents analysis and control design of a DFIG wind turbine with series grid side converter for ride through during unbalanced voltage sag events. A dynamic model and control structure is developed for unbalanced operating conditions.

M. Savaghebi, A. Jalilian, J. C. Vasquez, J. M. Guerrero[6] highlighted increasing interest in using distributed generators (DGs) not only to inject power into the grid but also to enhance the power quality. In this paper, a stationary-frame control method for voltage unbalance compensation in an islanded microgrid is proposed. This method was based on the proper control of DGs interface converters. The DGs are properly controlled to autonomously compensate for voltage unbalance while sharing the compensation effort and also active and reactive powers. The control system of the DGs mainly consists of active and reactive power droop controllers, a virtual impedance loop, voltage and current controllers, and an unbalance compensator.

In order to improve the power quality problems,

this project consisting of controllers based on fuzzy logic was proposed.

VOLTAGE UNBALANCE COMPENSATION IN DISTRIBUTED GENERATION

Distribution networks are sometimes related to the last level of any electrical system, the microgrids are designed and operated heretofore with a vertical organization in whichenergy transfer follows a prime to bottom pattern, that means this that energy goes from generationto transmission henceforth to distribution and at last to the shoppers. The distribution and transmission networks disagree considerably because of the objectives they weredesigned to meet. One in all the variations between these 2 systems is that the connectiontopology within the distribution level are generally radial, whereas the transmission has ameshed structure. This has got to do with the very fact that the distribution network wasn't designedfor the affiliation of power generation devices. Moreover, the lower voltage levels, powerrating necessities and shorter transmission distances within the distribution network decrementthe electrical phenomenon to resistance (X/R) magnitude relation. Transmission networks ar characterised by higher X/Rratios generally around seven, whereas the distribution network has values around 0.5. In the distribution network the DSO is that the operator answerable of maintaining satisfactory systemoperation. in an exceedingly ancient system, the DSO is liable for management, development and operation of the electricity distribution system in an exceedingly secur

and environmentally friendly manner.

3.1 *Voltage Unbalance*

Voltage unbalances square measure outlined as a condition wherever the (Root MeanSquare) RMS value of the section voltages or the section angles between consecutive phases in three-phase system aren't equal". it's a typical observe within the literature to use the termunbalance to explain each the section and amplitude. This observe supposes that unbalancesand asymmetries square measure constant, which could not be true. during this thesis the term "unbalance" willbe want to discuss with variations in RMS price whereas "assymetry" are going to be reserved specifically for point in time deviations. moreover, unbalances square measure a result of 3 general factors: terminal voltage of the generators, electric resistance of the electricity system and currents drawn by the loadsthroughout the transmission and distribution grid. First allow us to analyze the voltage unbalances originating from the transmission level. The voltage levels within a part of the generation square measure usually extremely regular andalso the variations inline impedances square measure because of the character of the transmission. Voltage unbalance is caused by a physical imbalance of generating and transmission instrumentation. so as to avoid these problems the transmission lines square measure converse with the target of maintaining the symmetry between the cables. If this can be not done this square measure permanent sources of unbalance within the grid thatcan become worst if the system is loaded with unbalanced load. Since the distribution system is that the last level of the electrical network the unbalances areusually a lot of infamous. The most supply of permanent voltage unbalance within the consumer level are electrical device bank affiliation, electrical device electric resistance, gear mechanism electric resistance, distribution network characteristics, three-phase and single-phase load magnitudes, load powerfactors, and transmission network voltage unbalance. Moreover, load variations associated with the various energy consumption habits of every client may additionally increase the whole unbalance within the system. In most sensible cases, the asymmetry ofloads is that the main reason for unbalance.

3.2 *DG Integration*

DG changes the classical Distribution Network management methodology that was used thus far. The energy injection within the shopper level and also the use of converters commissioned military officer grid interaction has animportant impact on the voltage profile and unbalance level of the system. Energy surplus originating from DER produces a reverse power be due the distribution network to the transmission as shown in Fig 3.1 Excess power can rise the voltage profile domestically. This voltage rise may be a steady-state result and it powerfully depends on the X/R magnitude relation, feeder load, injected power by the weight unit and also the short-circuit power of the grid at the purpose of interconnection. For the character of the distribution grid, the voltage changesare preponderantly a product of the active power. moreover, it's common observe in thetransmission network to live its strength with its X/R magnitude relation and contact Ratio (SCR). The SCR relates the nodes short-circuit power and also the rated power of a RES (typically a windfarm). Moreover, it's a typical observe to check the planning of a system underneath the worst casescenarios to asses that the network voltage profile is among the voltage limits. These situations are

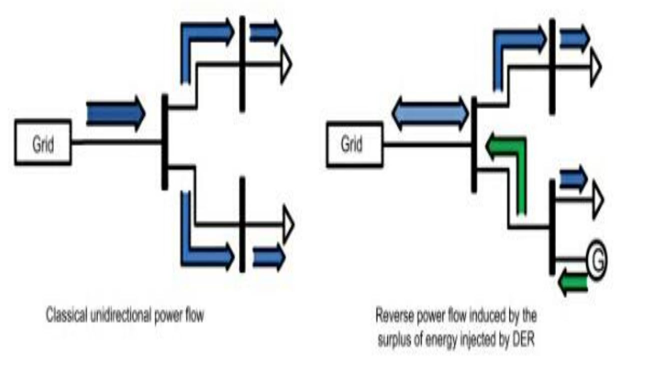

Figure 3.1: Classical and Reverse Power Flow

- no generation and maximum system demand
- maximum generation and maximum system demand
- maximum generation and minimum system demand

Untill now the consumers "regulate" the power output of power from the DER. The consumerswith DER will inject the maximum power they can depending on the weather conditions not onthe network requirements. If the voltage exceeds the limits corrective actions have to be applied.

Furthermore, the variability of energy injection from DER leads to a higher occurrence of theworst-case scenarios. High levels of DG penetration may even require additional scenarios to ensure that the system is within its boundaries.

Typically, sensitivity studies in the power system are done to better asses the correct operation of the network. Sensitivity is defined as the ratio of change relating small changes of some dependent variable to a small change of some dependent variable. For example, in powersystems it is a common practice to calculate the voltage sensitivity to active or reactive power. For this purpose, different study cases were done to analyze the impact of the relevant parameters.

DESIGN AND IMPLEMENTATION OF UNBALANCE COMPENSATOR

4.1Implementation with PI Controller

In this paper, the voltage unbalance compensation methodology is improved in terms of dominant the negative sequence voltage directly. because the reference of voltage controller is that the superposition of the output of unbalance compensator and droop controller. The

$$v_{cen} = \left[\left(\left| v^- \right|_{ref} - \sqrt{v_d^- + v_q^-} \right) \cdot PI_1(s) - Q^- \right] \cdot PI_2(s) \cdot \frac{v_{dq}^-}{\sqrt{v_d^- + v_q^-}} \quad (4$$

mathematical description of the unbalance compensator implemented in synchronous reference (*dq*) frame as given by the equation 4.1 below.

Where

V_{cen} is the control signal send to inverter local controller

$|V^-|_{ref}$ is the reference of negative sequence voltage

$Q-$ is the negative sequence reactive power at point of common coupling (*PCC*)V^-_d and V^-_q are the *dq* components of negative sequence voltage respectively $PI_1(s)$ and $PI_2(s)$ are the negative sequence voltage controllers, respectively.

It can be seen that the voltage unbalance level is mitigated by controlling the *PCC* voltage directly while the negative sequence reactive power injection is controlled indirectly. Detailed algorithm of the unbalance compensator is depicted in figure 4.1. As it can be seen, *dq* components of the negative sequence voltage at *PCC* is first extracted by rotating V_{PCC} with negative angular frequency $-\omega$ and then followed by a low pass filter(*LPF*). Furthermore, the amplitude of negative sequence voltage $|v-|$ is calculated with filtered V^-_d and V^-_q and is afterwards send to a *PI* controller to generate the reference of negative sequence reactive power Q^-_{ref}. Another *PI* controller fed with the error of Q^-_{ref} and $Q-$ is implemented here to enhance the dynamic behavior of the unbalance compensator. Finally, the output of the *PI* controller is multiplied by normalized $v-$ and transformed to $\alpha\beta$ coordinates to generate the compensation signal which is send to the voltage loop controller.

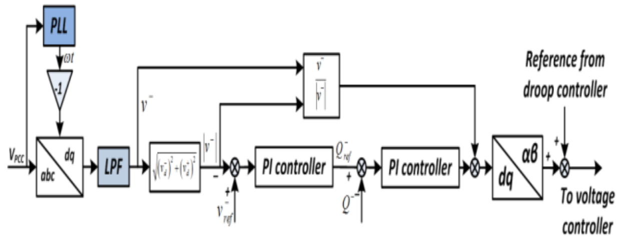

Figure 4.1 Block diagram of the proposed unbalance compensator with PI Controll

4.2 Design of Fuzzy Logic Controller

The FUZZY logic Controller is especially containing of 4 principal elements as shown within the figure below.

Fuzzification

Fuzzy rule Base

Fuzzy reasoning

Defuzzification

The workingof FUZZY logic Controller is explained as follows.

Fuzzification: Fuzzification is that the method wherever the crisp quantities square measure reborn to fuzzy. broadly speaking functions of Fuzzification classified as:

Determine the worth of input variables. Scale Mapping technique i.e., converts the vary of input variables values into corresponding universe of discourse.

Fuzzification i.e., converts computer file into appropriate linguistic worth which can be viewed as labels of fuzzy sets.

Fuzzy Rule Base: Fuzzy system consists of expert knowledge-based set of linguistic statements. The Knowledge base included the knowledge of the system on which fuzzy rules need to be applied and the attendant control gains. It consists of a "data base" and a "rule base":

The data base includes necessary definitionsat are required to define linguistic control rules and fuzzy data manipulation in an FLC.

The rule base characterizes the control goals and control policy of the domain experts by means of a set of linguistic control rules.

Fuzzy Inference: Fuzzy illation is that the core of a symbolic logic controller, its main operate is to simulate human selections supported fuzzy ideas and of confirm fuzzy management actions by applying the foundations of illation in symbolic logic. In illation engine, fuzzy 'IF-THEN' rules from fuzzy rule base square measure accustomed map fuzzy input sets to fuzzy output sets.

Defuzzification: The Defuzzification performs the following functions:

Scale Mapping i.e., converts the vary of values of output variables into corresponding universe of discourse.

The output additionally contains a set of member-shipfunctions.These membership functions outline the t potential responses and outputs of the system.

Performs a non-fuzzy management action from. ana inferred fuzzy management action.

Thevarious defuzzification strategiesare: a Max-Membership principle, centre of mass methodology, weighted average methodology, Mean-max membership, Centre of sums, Centre of largest space, initial of maxima or last of maxima.

4.3 Steps for Building a Fuzzy Logic Controller

Determine the values of input and output variables.

Get management data by information analysis.

Assign membership functions for input and output fuzzy variables.

Determine fuzzy rules.

Tune membership functions and rules by variable the dimensions of membership functions and rules.

In addition, style of formal logic controller will give fascinating each tiny signal and huge signal dynamic performance at same time, that isn't potential with linear management technique. the event of formal logic approach here is restricted to the look and structure of the controller. The inputs of FLC ar outlined because the voltage error, and alter of error and Duty cycle is that the output to the formal logic Controller. Fuzzy sets ar outlined for every input and output variable as delineated below.

5 triangular membership functions ar chosen the for-input variables and therefore the output variable, namely: NB, NS, Z, PS and PB, representing negative huge, negative tiny, zero and positive tiny and positive huge, severally, within the investigation enforced victimisation the membership perform editor as represented in figure 4.2 to 4.4. A fuzzy illation system file is developed with the triangular membership functions as shown in figure 4.7 with the assistance of FIS editor on the market within the MATLAB/Simulink.

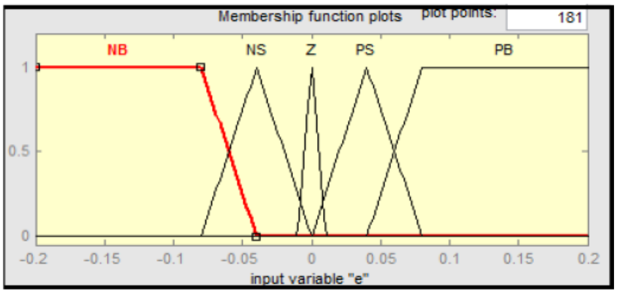

Figure 4.2Error as input

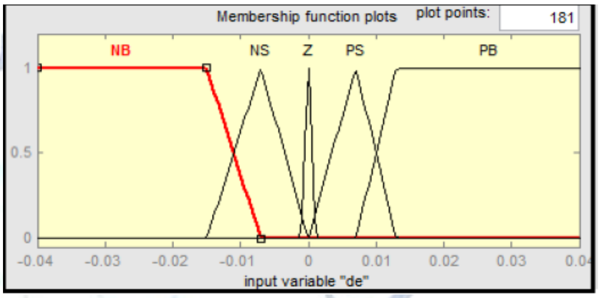

Figure 4.3 Change in Error as input

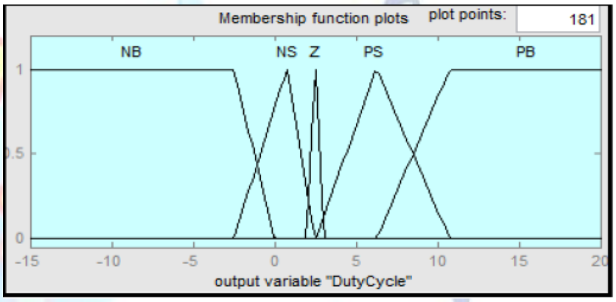

Figure 4.4Output variables to defuzzification process

In the decision-making method, there's rule base that links between input (error signal) and sign. Table 4.1 and figure 4.5 – 4.6shows the rule base exercised during this projected mathematical logic Controller.

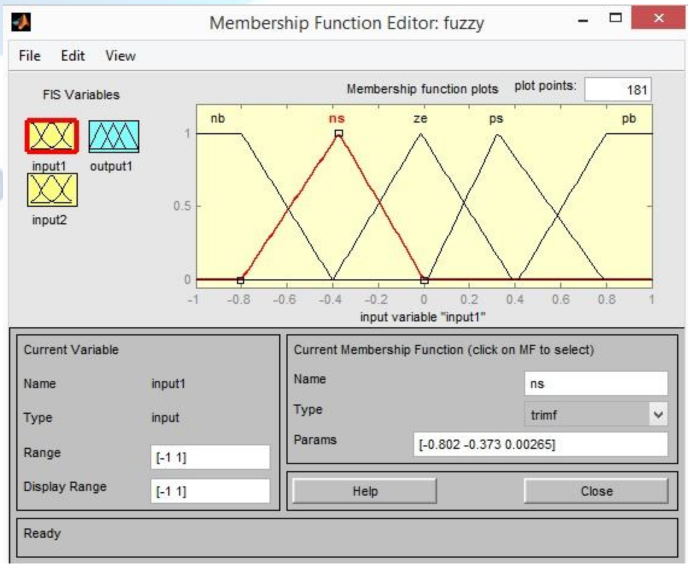

Figure 4.5Membership functions for the FLC of the proposed model

Table 4.1 Fuzzy Rule Representation

e \ de	NB	NS	Z	PS	PB
NB	PB	PS	NS	NS	NB
NS	PS	PS	NS	PB	NB
Z	NB	NB	NS	PS	PB
PS	NS	NS	PB	NB	PS
PB	NS	NS	PB	PB	PB

The basic fuzzy rules are framed using the rule editor available in the MATLAB environment.

The set of twenty five fuzzy rules applied whereas modeling for the controller as shown in fig 4.6. the essential rule of FLC offers the connection between the input and output. The Rule base characterizes the management goals and management policy of the domain specialists by means that of set linguistic management rules. The wide used technique within the FLC style is that the Mamdani technique within which a min–max integrative rule of abstract thought was adopted supported associate interpretation of a sway rule as a conjunction of the antecedent and resulting. The rule viewer of the FLCs employed in the model is shown Figure 4.7.

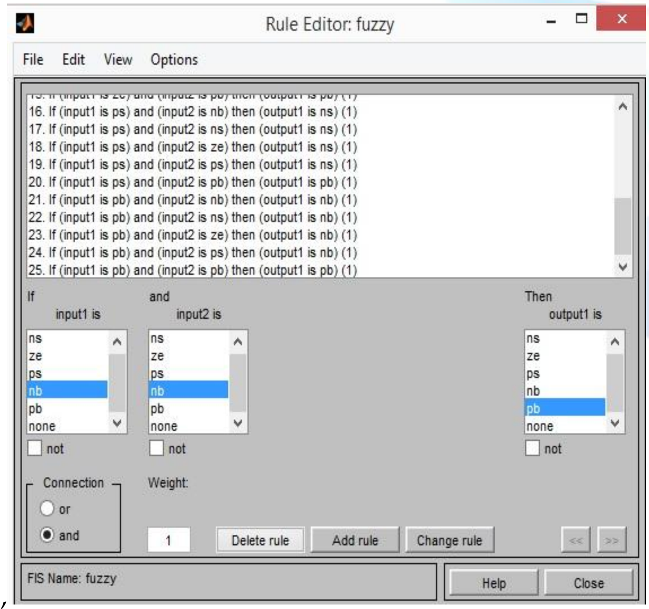

Figure 4.6Fuzzy rules for the proposed Fuzzy controller

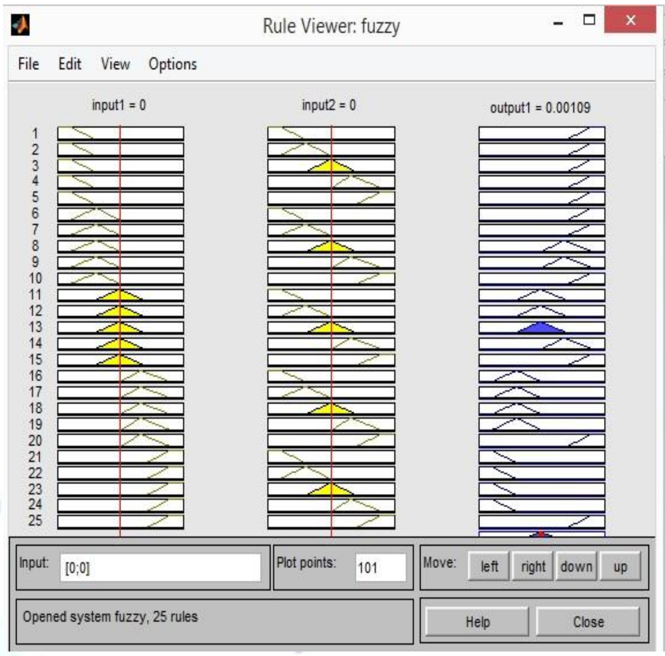

Figure 4.7 Rule viewer of the proposed model

SIMULATION RESULTS

5.1 Simulation Results with PI Controller:

By running the simulink model in the MATLAB software the results given below were obtained:

Before t=0.1s, an unbalanced linear load is connected to the common AC bus and lead to the flowing of negative sequence current. Thus, voltage unbalance appears on the PCC voltage.

At t=0.1s, the direct unbalance compensation loop with PI controller is enabled and then the corresponding compensation signal is sent to the DGs local controller. The unbalance voltages significantly reduced as shown in the below figure.

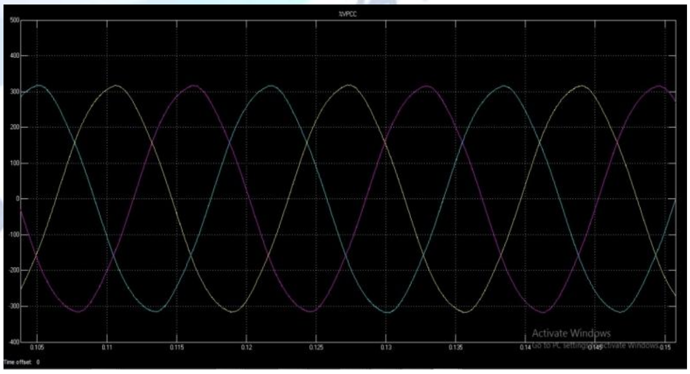

Figure 5.1PCC voltages after compensation

In addition, the unbalance factor significantly reduced from 5% to 1% after few seconds as shown in figure 5.2. Note that the unbalance factor (UF) is defined by the equation

$$UF = \sqrt{\frac{(v_d^-)^2 + (v_q^-)^2}{(v_d^+)^2 + (v_q^+)^2}} \cdot 100$$

Where V_d+ and V_q+ are the positive sequence of the PCC voltage respectively;

V_d- and V_q- are the negative sequence of the PCC voltage respectively.

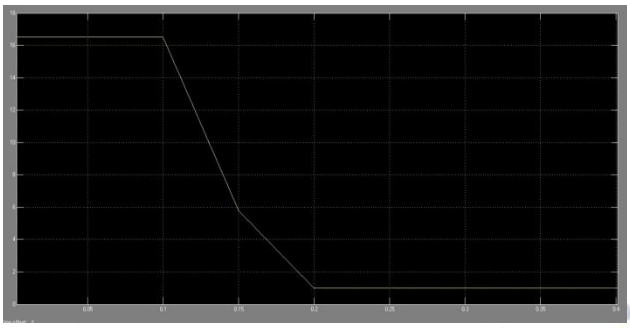

Figure 5.2PCC voltage unbalance factor

To better illustrate the effect of the unbalance compensator, the negative sequence voltage at PCC is shown in figure 5.3

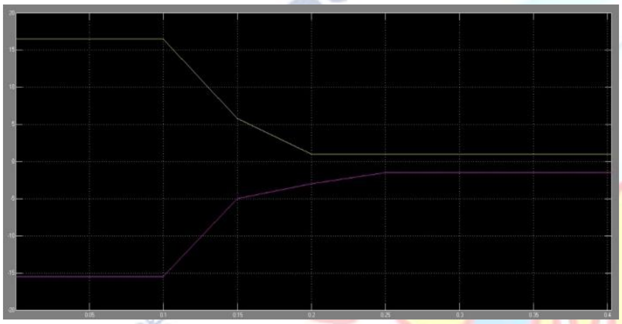

Figure 5.3 Negative sequence voltage of PCC

From the figure 5.3 it is obvious that the PCC negative sequence voltage drops dramatically after the compensation enabled.

The output voltage of the DERs sharing common bus has a good voltage quality, as illustrated in figure 5.4 below with the decrease of the PCC voltage unbalance factor which is achieved by means of deteriorating the DGs output voltage.

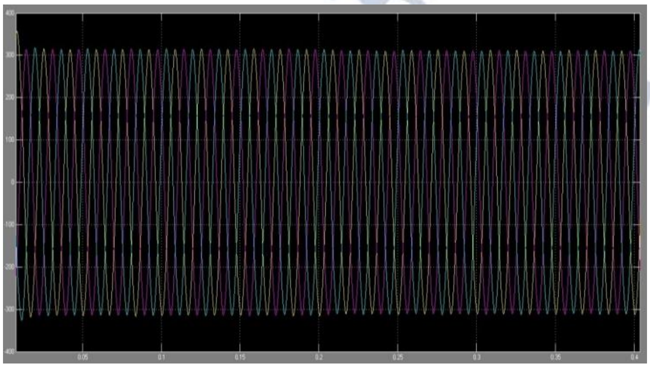

Figure 5.4Output voltages of DER before and after compensation

The following graphs show the THD analysis of the control system with and without PI controller for the PCC voltage.

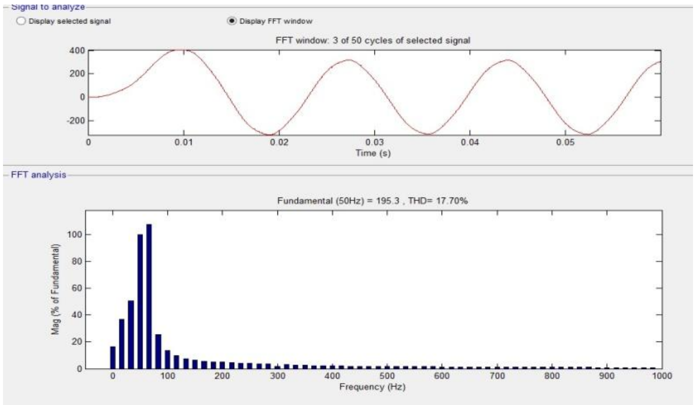

Figure 5.5%THD without compensation

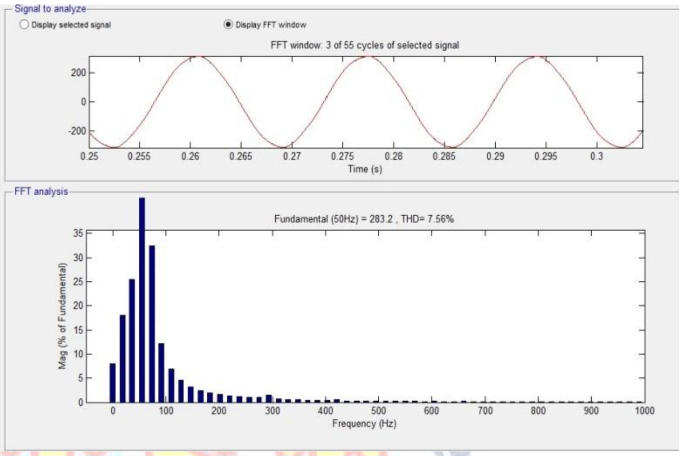

Figure 5.6%THD with PI controller

5.2 Simulations Results with Fuzzy Logic Controller

The below simulation diagram shows the projected voltage unbalance compensator with the implementation of FUZZY logic controller

At t=0.05s, the direct unbalance compensation loop with fuzzy controller is enabled so the corresponding compensation signal is distributed to the DGs native controller. The unbalance voltages a lot of considerably reduced as shown within the below figure 5.7

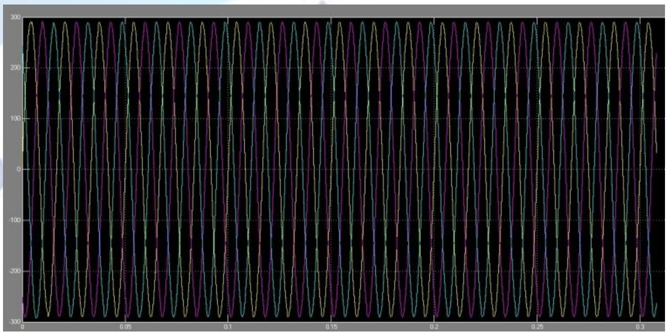

Figure 5.7PCC voltages after compensation with Fuzzy Logic Controller

In addition, the unbalance factor significantly reduced from 5% to 0.8% after few seconds as shown in figure 5.8

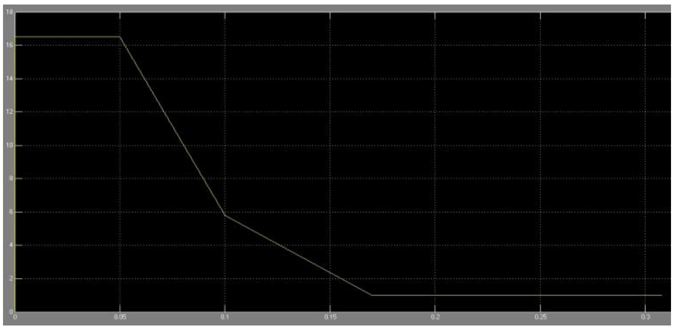

Figure 5.8 PCC voltage unbalance factor with Fuzzy Logic Controller

The negative sequence voltage at PCC is shown in figure five.9 for higher illustration of the impact of unbalance compensator victimization symbolic logic Controller. From the figure 5.9, it is obvious that the PCC negative sequence voltage drops dramatically once the compensation enabled.

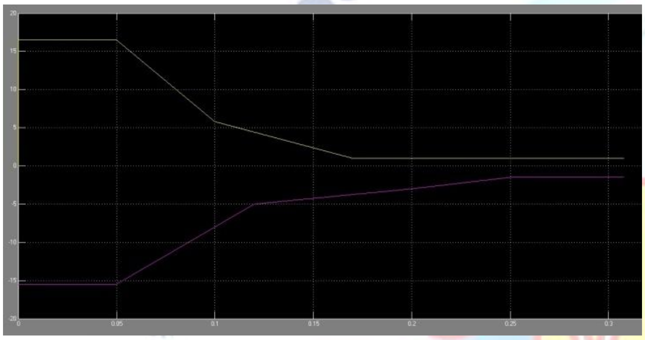

Figure 5.9 Negative sequence voltage of PCC using Fuzzy Logic Controller

The output voltages of the 2 DERs sharing a typical bus area unit illustrated in figure five.10 below victimization formal logic Controller. It is seen that the 2 DERs have the nice power sharing accuracy.

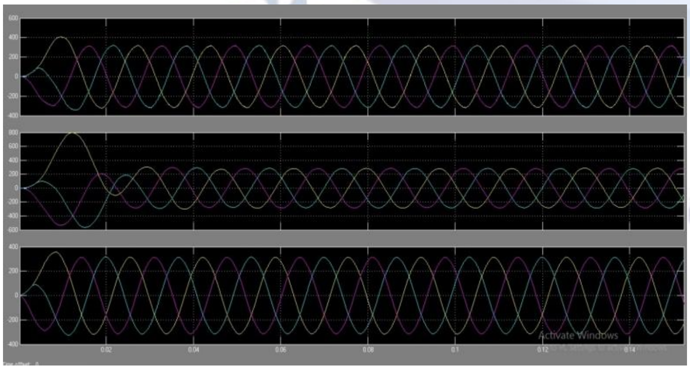

Figure 5.10 Output voltages of DER1 and DER2 after compensation

The following graphs show the THD analysis of the control system with Fuzzy Logic Controller for the PCC voltage.

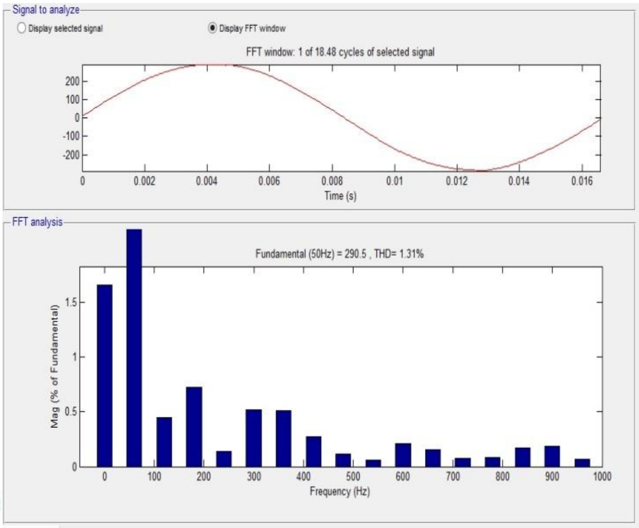

Figure .5.11 %THD with Fuzzy controller

CONCLUSIONS

In this paper, a novel direct voltage unbalance compensation control strategy for islanded microgrid has been investigated. The control structure includes two levels: a local controller and a direct voltage unbalance compensator. The local controller mainly takes care of the bus voltage regulation and the power sharing accuracy, while the direct voltage unbalance compensator contributes to mitigate the voltage unbalance at the *PCC* by controlling the voltage reference. This voltage unbalance compensator is proposed with PI Controller and Fuzzy Logic Controller. The effectiveness of the control scheme has been validated with twoDG converters connected in parallel sharing a common AC bus. The experimental results of Fuzzy logic scheme shows that the negative sequence voltage can be well suppressed to the desired value with a satisfied load sharing accuracy when compared with PI Controller.

FUTURE SCOPE:

The proposed schemes can be further extended for voltage and current unbalance compensation with more than two DERs sharing the common bus in a Microgrid. Also, a general approach towards standardization with hierarchical control of droop-controlled using various compensators can be utilized in AC and DC Microgrids. Further, methods like ANN and GA for optimizing the gains of PI control can be approached for better accuracy.

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