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Power Quality Enhancement Capability of Grid Connected Parallel DFIG Units

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Abstract: Wind power is the widely used renewable source of energy specially doubly fed induction generators (DFIG) when operated in parallel units disbalances the grid profile in a grid connected mode. Hence a proper control strategy has to be employed to maintain voltage unbalance and harmonics at the point of common coupling (PCC). In this paper a PI controller based converter is designed to assist the grid connected operation of parallel DFIG units. The controller integrates the unit with grid and regulates the voltage at PCC also it reduces the harmonics of the system. The proposed controller has been tested for constat wind speed as well as variable wind speed operation. Also the system has been analyzed for the loading conditions and fault to check the operability of the controller.

I. INTRODUCTION

As the penetration of the wind power is increasing, their controllability has to be enhanced to harness the maximum output from it. For bulk power generation Doubly Fed Induction Generator (DFIG) is the most popular and reliable wind energy generation system. Its ease of controllability and smooth operation in variable wind speed makes it widely acceptable form of renewable generation system. As the penetration OF DFIG grid connected mode is increasing in modern power system, there is a focus interest in using wind farms not only to inject power into the grid but also to improve the grid profile in terms of power quality, such as compensating the voltage unbalance at PCC[1]–[5]. To achieve this target, two important issues have to be addressed: 1) the basic controlled operation at PCC; and 2) the compensation effort meet the power requirement as well as to improve the power quality of the system. In literature basic compensation strategies for DFIG units in grid connected mode have been [2]–[4]. However, these strategies are complicated to apply for parallel units in grid connected operation, since neither the total compensation effort of the whole wind farm, nor the compensation effort sharing among DFIGs, is flexible. Actually, the coordinated control of parallel DFIG units with grid integration is a conflicted process since the synch of different unit itself is complicated that too with grid integration. For example, the DFIG with high load should share less pay exertion, and the aggregate remuneration exertion of the entire breeze ranch ought to likewise be decreased when the breeze is solid. Hence to increase the profitability the network must be adaptably control the voltage unbalance factor (VUF) at PCC; the tradeoff can be accomplished between the DFIG task execution and the PCC control quality. In this papera PI controller based converter is designed to assist the grid connected operation of parallel DFIG units. The proposed controller controls the grid parameter as well as rotor parameter simultaneously. As a result of which the flow of real and reactive power at PCC becomes smooth. The controller integrates the unit with grid and regulates the voltage at PCC also it reduces the harmonics of the system the proposed controller has been tested for constant wind speed as well as variable wind speed operation.

II. DFIG BASIC OPERATION

Doubly Fed Induction Generator, as the name suggests got two winding; magnetic field winding and armature winding which are separately connected to external equipments. The working principle is same as all the rotating machines has. Fig-1 shows the constructional feature of DFIG. AC generators and DFIG are similar in constructional features but, DFIG is different in a sense that it can be operated at variable speed that's why they are sustainable as variable speed wind generation system. The DFIG is a combination of four technologies aerodynamic, mechanical, electromagnetic, and electronic systems. Due to the ability of DFIG to operate in a variable wind speed conditions, its application as a wind power generation system is increasing day by day. The DFIG's principle of working as an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. As mentioned earlier, DFIG is fed from two ends, one end of the generator is connected to the grid and another end is to the two back to back voltage source converters (VSC). The VSC is designed using three phase 2 level universal bridge with three arms. Both the inverters are linked with Dc link capacitor to stop circulation of leakage current and proper matching of inverters. At both the ends of converter filters are connected. Generator has two windings; one winding is directly connected to the output, and produces 3-phase AC power at the desired grid frequency. The other winding (traditionally called the field, but here both windings can be outputs) is connected to 3-phase AC power at variable frequency. This input power is adjusted in frequency and phase to compensate for changes in speed of the turbine.

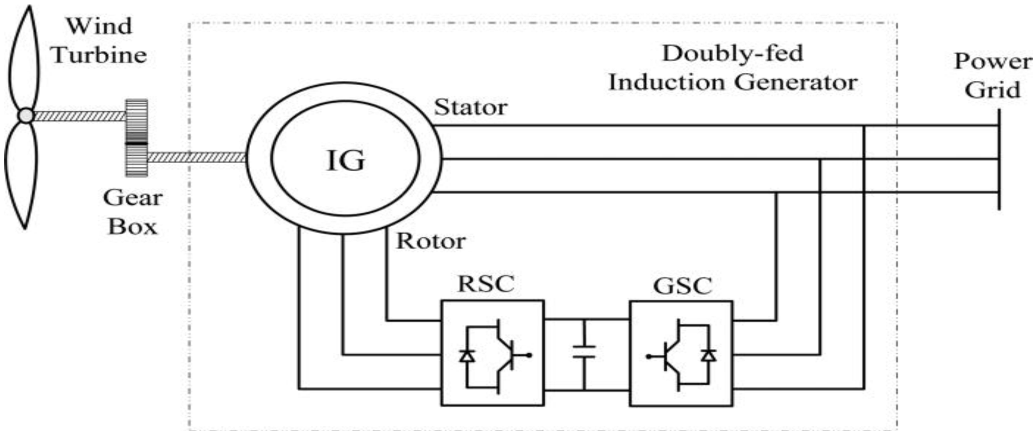

Figure-1 Schematic of a Double Fed Induction Generator connected to a wind turbine

III. PARALLEL UNITS OF GRID CONNECTED DFIG

Parallel operation of DFIG units as shown in figure 2 demands precise control since each unit has to be synchronized at same frequencies and reference signals. The coordinated controlled operation of grid connected parallel DFIG units is the main focus of this work. For parallel operation of DFIGs, injection of unbalance current methods has been reported in [9-13]. In [14]–[17], progressive control structures were utilized to adaptably control the VUF at PCC and offer the unbalance current among generators, while the ongoing correspondence was required. Be that as it may, the unavoidable postponement of ongoing communication may hazard the activity steadiness of wind ranches [18], [19], since the correspondence framework for a breeze cultivate is composed mostly for the occasionally changing financial dispatch summons, instead of the real time various leveled control. An independent control procedure was proposed in [20] to adaptably control the VUF at PCC and self-governing mode shares the unbalance current among generators by changing the unbalance compensation gain (UCG), while the VUF control and the reactive power sharing are uncertain what's more, the framework is naturally unsteady when UCG is moderately substantial. In [21], a Z– H droop control is adapted to decrease the powerful feeder impedance; therefore, the symphonious current can be self-rulingly shared by the individual working states of generators. Be that as it may, this methodology isn't appropriate when the sustaining lines are short, since the feeder impedances are too little to possibly be additionally decreased. In [22], the negative virtual inductance is utilized to check the feeder inductance, and after that the virtual protection is adaptively balanced as indicated by the rest of the limit, which can accomplish the self-governing sharing of symphonious current. Be that as it may, the aggregate symphonious bending (THD) at PCC, comparing to the VUF when considering the unbalance issue, is wild. In [23], both the THD at PCC and the rest of the limit of the generator are utilized to modify the coefficient G, at that point the controllable PCC voltage and self-ruling consonant current sharing can both be accomplished. In any case, the PCC voltage, instead of the nearby yield voltage, is utilized as a part of the control circle, which requires additional sensors and correspondence lines [24]. In [25] an auxiliary control circle is intended to accomplish the controllable VUF at PCC, and also self-governing sharing of negative grouping current among DFIGs and matrix side converters (GSCs) concurring to their separate residual limits.

The PCC voltage unbalance compensation for grid connected operation of parallel DFIGs can be achieved with flexible and autonomous control of the parallel DFIG stators and GSCs. In the proposed controller this can be achieved by referencing the grid signal to design the control signal using PLL and abc-dq transform.

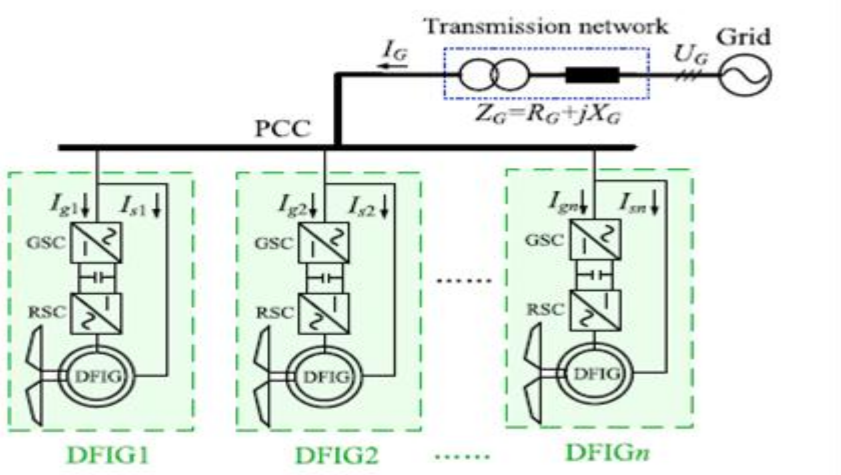

Figure-2Grid connected parallel DFIG units

The function of this controller can be defined with the following blocks;

i) The PCC voltage control block is used to track the VUF reference with a PI controller.

ii) The negative sequence current sharing block is used to produce the weighting factor for the output of the PCC voltage control block.

iii) The feed forward block is used to improve the dynamic response when the VUF reference steps rapidly.

IV. SIMULATION AND RESULT DISCUSSION

In this paper a weak grid is connected to parallel DFIG units. A grid side controller (GSC) is developed to compensate the voltage unbalance at PCC for autonomous operation of multiple DFIG units. In this paper two DFIG units are considered for parallel operation. The performance analysis for both constant speed and variable speed for the parallel DFIG units are studied under following cases;

Case 1(Figure 3); In this case electrical distance between the DFIG and the PCC is considered negligible hence the PCC voltage is replaced with the DFIG stator voltage. Rotor side converter (RSC) regulates the average stator active and reactive power outputs, and the GSC is controlled to keep the dc-link voltage stable. Unbalanced PCC voltage can be caused for various reasons, i.e., unbalanced local loads, unbalanced transmission line impedance, fault in any part of the system and so on [17].

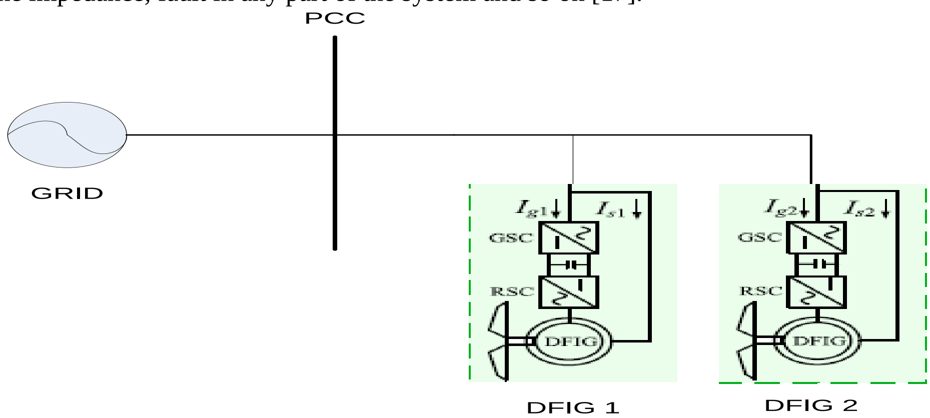

Figure 3 Parallel operations of DFIG units without considering electrical distances.

Case 2 (Figure 2); In this case electrical distance between the DFIG and the PCC is considered. One transformer is connected between grid and 30 km line and another is connected between line and DFIG. The voltage of PCC is not same as DFIG stator voltage and any deviation in PCC voltage may affect the DFIG performance and vice versa. Hence a controller is customized which can control the VUF at both the ends.

In both the above mentioned cases the system performance is analyzed with and without grid side and rotor side converter and results shows that the designed converter controls the voltage unbalance smoothly. The converter is customized using abc-dq transform, PLL, PI controller and active filtering element. The sinusoidal input is fed to abc-dq transform where three phase sinusoidal signal is converted into equivalent and two phase signal which simplifies the control design. The phase lock loop synchronizes the controlled voltage signal with the grid. The PI control generates the equivalent gain function so that triggering of the universal bridge can be

controlled. The harmonic or distortion can be filter out using active filter. Here inductance and capacitance of suitable rating is connected. The result for the cases mentioned is discussed in detail below.
The parameter selection for the proposed work is presented in Table 1.

Table-1 Component and rating used in the proposed topology.

DFIG unit parameter selection		**Grid unit parameter selection**	
PARAMETER	**RATINGS**	**PARAMETER**	**RATINGS**
DFIG rating each	1.5 MW	Grid voltage	120KV
Stator voltage	570 V	Transformer	6*1.75MVA
Frequency	50Hz	Line resistance	0.11 ohm
Lf	4.41mH	Line inductance	1.05mH
Cf	0.5e-6	Kp	0.04
DC-link capacitance	900e-6	Ki	500

- **Simulation results for Parallel operation of DFIG units without PI controller at constant speed.**

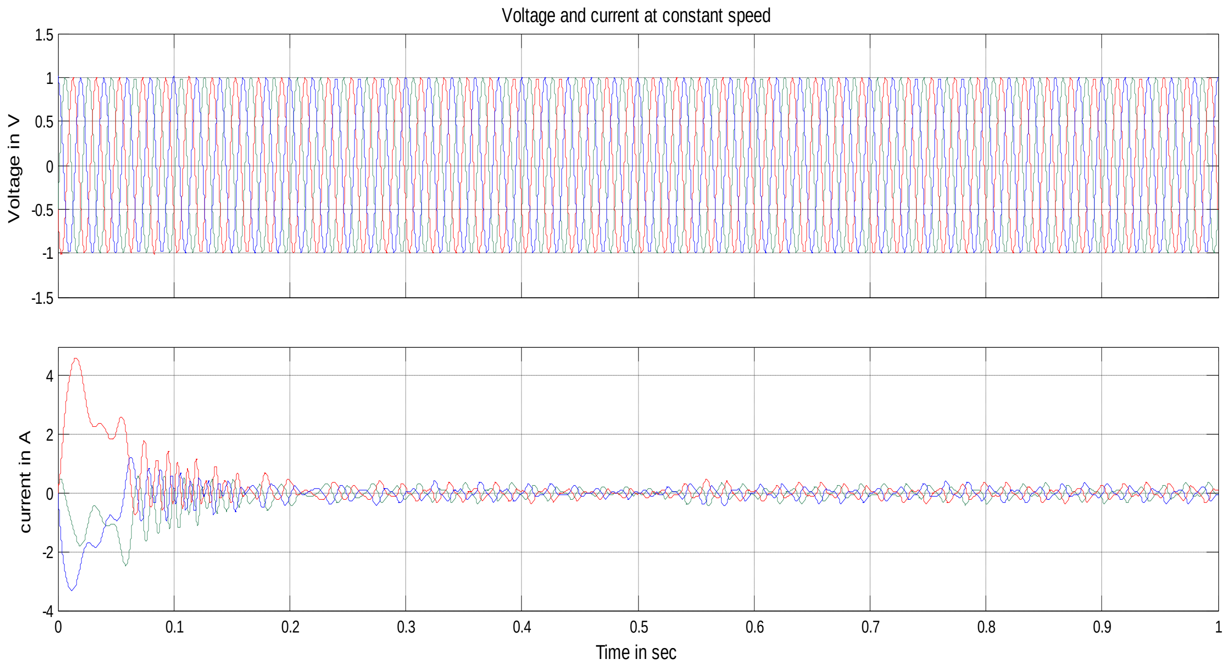

Figure-4Voltage and current at PCC for Parallel operation of DFIG units without PI controller at constant speed

- **Simulation results for Parallel operation of DFIG units without PI controller at variable speed.**

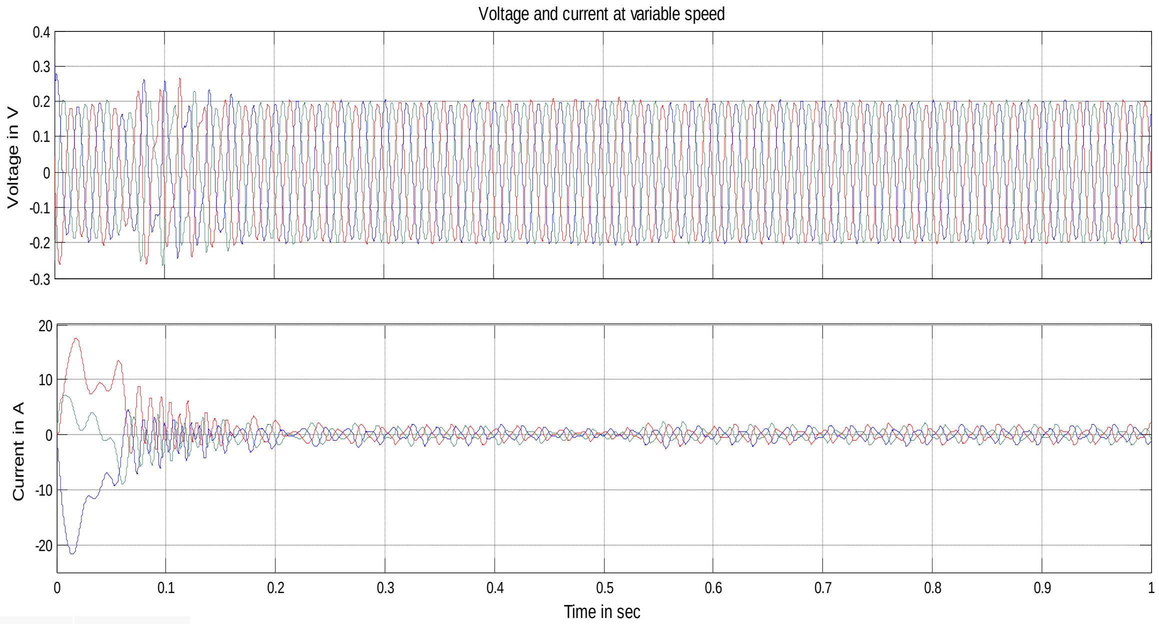

Figure-5 Voltage and current at PCC for Parallel operation of DFIG units without PI controller at variable speed.

- **Simulation results for Parallel operation of DFIG units with PI controller at constant speed.**

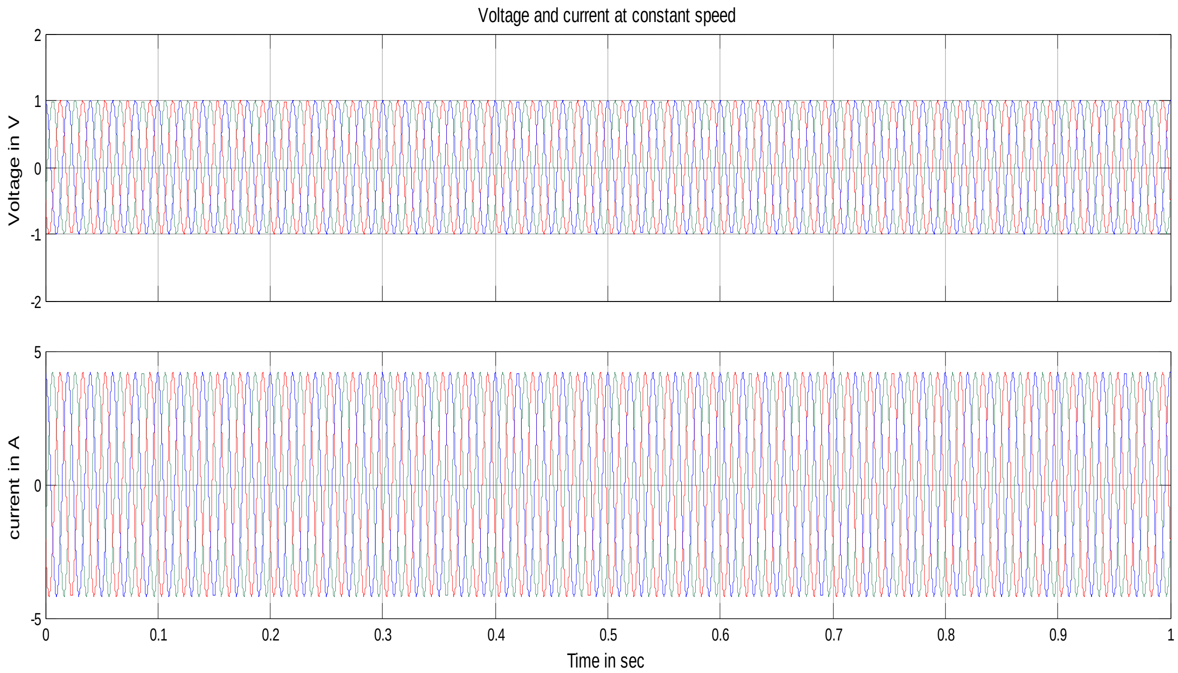

Figure-6 Voltage and current at PCC for Parallel operation of DFIG units with PI controller at constant speed.

- **Simulation results for Parallel operation of DFIG units with PI controller at constant speed.**

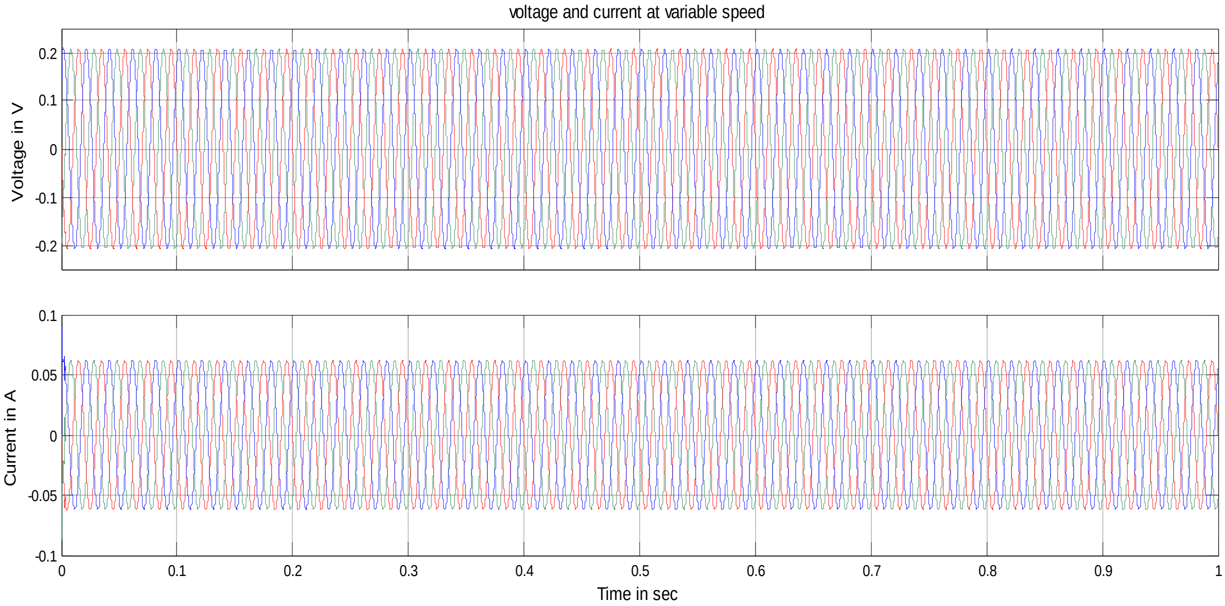

Figure-7 Voltage and current at PCC for Parallel operation of DFIG units with PI controller at variable speed.

- **PCC Voltage Unbalance Factor (VUF)**

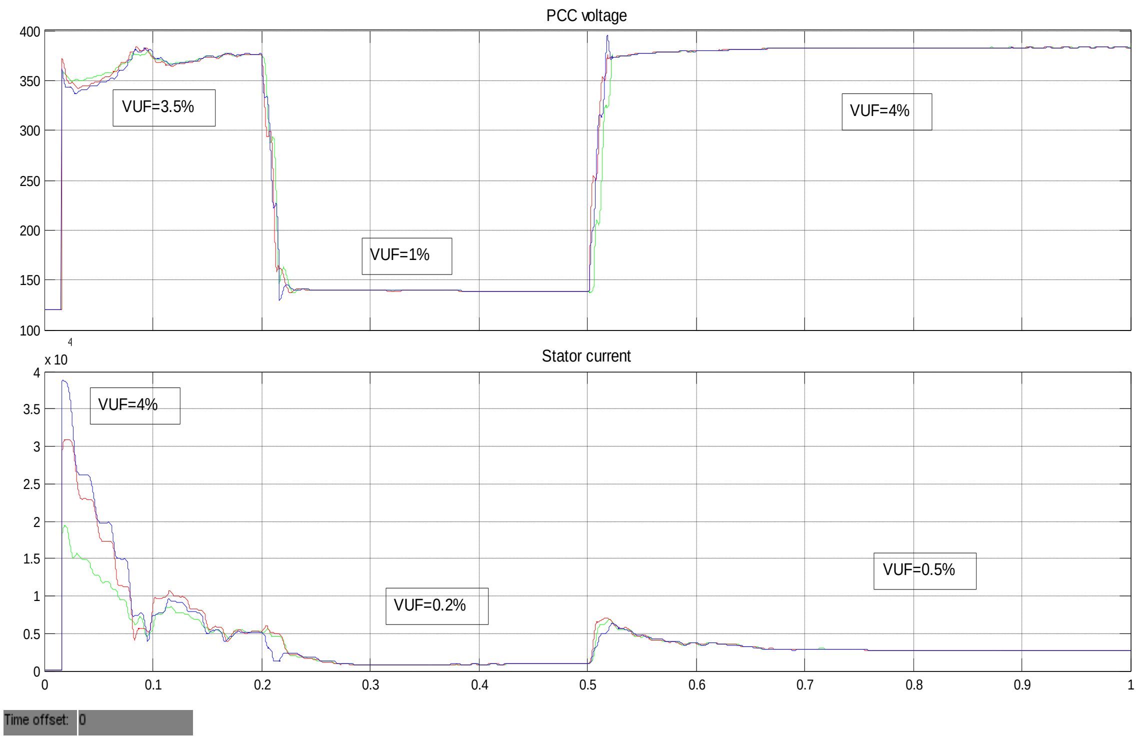

Figure-8 Output voltage and current for regulated VUF at PCC

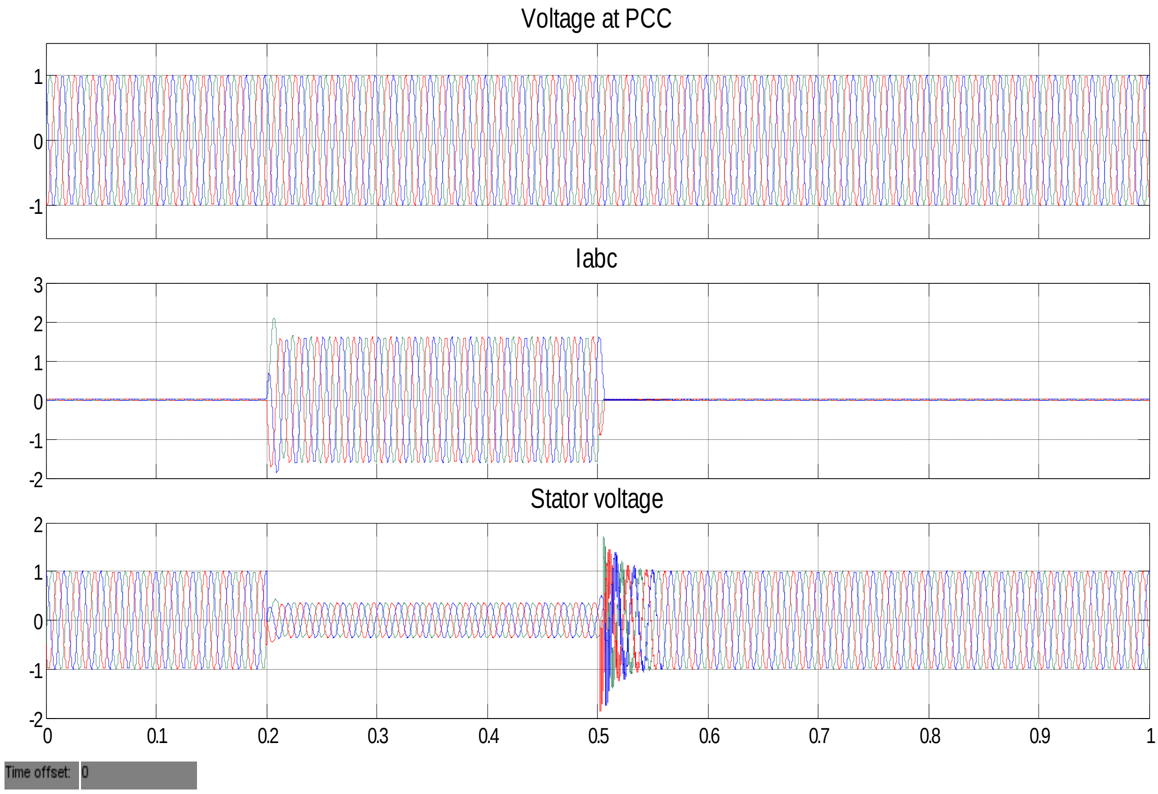

Figure-9 Simulation results of PCC VUF flexible control.

Figure 8 and 9 presents voltage unbalance condition for parallel DFIG operation. Voltage deviation 5% to 1 %. When GSC and RSC controller are connected, it can be seen in Fig. 8 that the VUF at PCC can be flexibly controlled from 6% to 0.2%, and the output negative sequence current of the DFIG systems increases with the decrease of the VUF at PCC. Thus, it can be concluded that the flexible tradeoff between balanced output current and balanced PCC voltage is achieved.

V. CONCLUSION

A flexible compensation strategy for parallel DFIGs is presented when connected to grid for voltage restoration capability enhancement. In this work a PI control designed to control DFIG units as well as grid profile which could continuously control the VUF at PCC. Thus, the flexible tradeoff between the balanced output current and the balanced PCC voltage could be achieved. The RSC and GSCs as per there capability automatically compensate the PCC voltage and stator voltage of the DFIG units capacity without real-time communication. The problem of the VUF measuring deviation among different DFIGs was solved with the proposed dead-band PI controller in the secondary control loop. The theoretical analysis and the simulation have shown the effectiveness and good control performance of the proposed strategy.

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