Hierarchical Droop Control strategy Based Reactive Power Management in Micro grid

B. Bhaskar, M.V. Rambabu, A. Suresh
Department of EEE, CITS Warangal, Telangana.

Abstract: *A micro grid (MG) is a local energy system consisting of a number of energy sources (e.g., wind turbine or solar panels among others), energy storage units, and loads that operate connected to the main electrical grid or autonomously. MGs provide flexibility, reduce the main electricity grid dependence, and contribute to changing large centralized production paradigm to local and distributed generation. However, such energy systems require complex management, advanced control, and optimization. Moreover, the power electronics converters have to be used to correct energy conversion and be interconnected through common control structure is necessary. Classical droop control system is often implemented in MG. It allows correct operation of parallel voltage source converters in grid connection, as well as islanded mode of operation. However, it requires complex power management algorithms, especially in islanded MGs, which balance the system and improves reliability. The novel reactive power sharing algorithm is developed, which takes into account the converters parameters as apparent power limit and maximum active power. The developed solution is verified in simulation and compared with other known reactive power control methods.*

1. INTRODUCTION

Micro grid (MG) is a separate system that produces and storages electrical energy, which consists of renewable energy sources (RES), local loads, and energy storage based on batteries or super capacitors. It is inherent part of modern and popular smart grids which includes also intelligent buildings, electrical car stations, etc. All RES are using power electronics devices (e.g., converters), which number significantly increasing and costs decreasing in range 1%–5% every year . RES are usually connected to the grid and many installations cause the parallel operation of RES close to each other. Digital Object Identifier of the classical structure of electrical power systems, toward new solution containing distributed generation, energy storage, protection and control technologies, and improving their performances. MG is highly advanced system from control and communication point of view. It has to manage power for local loads as well as control all converters with high efficiency and accuracy especially when MG operates as islanded system. Islanding mode of operation provide the uninterruptible power supply for local loads during grid faults. The performances of islanded MG are specified according to IEEE Standard 1547.4 [9]. With increasing number of RES applications, operating parallel, close to each other (few km) and with developed islanded mode of operation, the MGs are become perfect solution for RES integration. Fundamental algorithms of ac MGs, described in are based on master–slave control or hierarchical droop control. The first solution includes only one converter with voltage control loop (VCL), operating as a master, and others operating in current control loop (CCL)—slaves. The produced power is controlled by sources with CCL and the voltage amplitude and frequency is keeping in point of common coupling (PCC) by master unit. Disadvantage of this solution is no possibility to connect other VCL sources to MG, which are the most popular and used RES solutions. The second control solution, called droop control, includes many VCL sources and provides possibility to many different RES interconnection. The idea of droop control is based on active and reactive power related to voltage frequency and amplitude droop on coupled impedances. Unfortunately, classical droop control method with proportional droop coefficients does not provides proper reactive power sharing between converters connected to common ac bus. In classical approach, the equal reactive power sharing (ERPS) can be obtained only when active powers are equal and droop coefficients are well chosen. When active powers are changing, the reactive power sharing cannot be controlled causing overload or reactive power circulation between converters. Moreover, the important issue in droop control is static trade-off between voltage regulation and reactive power For increasing reactive power, the voltage droop on converter's output impedance also increase, what may cause overvoltage. In order to provide appropriate power sharing and minimize the risk of converter damage the many additional aspects (e.g., nominal apparent power Fig.

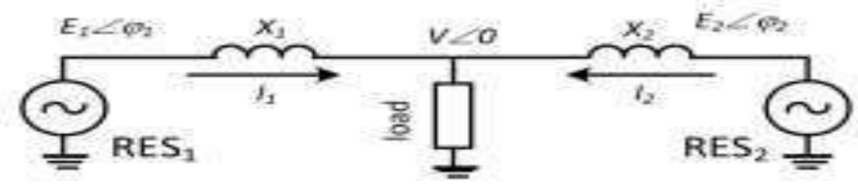


Fig. 1. Equivalent circuit of parallel connected VSIs.

Connected VSIs. instantaneous active power, nominal voltage of converter) have to be considered in control system. There are only few papers describing reactive power sharing between parallel operating converters in islanded ac MGs. The researchers focused on ERPS between all RES usually controlled by MG central control unit or implemented as virtual impedances. From the other hand, researches consider reactive power sharing in order to optimize transmission power losses by appropriate optimization algorithm (e.g., particle swarm optimization) which can be neglected in MGs, hence the short distances and the line impedances are low. However, algorithms described in literature are not considering capabilities of single RES, which have limited apparent power. If active power, usually calculated from maximum peak power tracking (MPPT) algorithms obtain almost nominal apparent converter limit the equal power sharing algorithms cannot be used, because the overload can occur, what leads to damage or exclusion from operation of RES unit.

II. CLASSICAL DROOP CONTROL

When at least two RES are connected through energy converters to the MG, the droop control method is often applied what provides the correct parallel operation of voltage source converters (VSI). The equivalent circuit of two converters connected to common ac MG bus can be presented by Fig. 1. Presented scheme is similar to the equivalent circuit of synchronous generator, hence the active and reactive power of kth converter connected to ac MG can be described as P, active power; E, converter voltage amplitude; V, voltage amplitude in PCC; X, coupling impedance; and φ, angle of converter voltage (see Fig. 1).

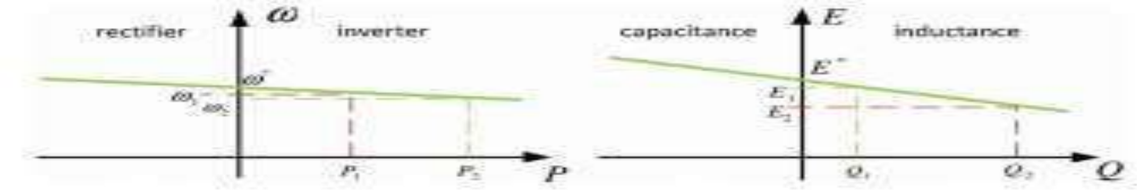


Fig. 2. P–ω and Q–E droop characteristics.

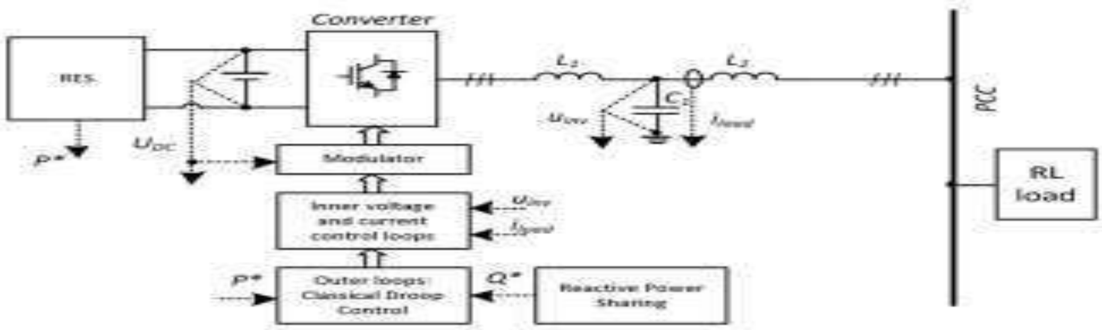


Fig. 3. Block scheme of control structure for one of the converters in islanded MG.

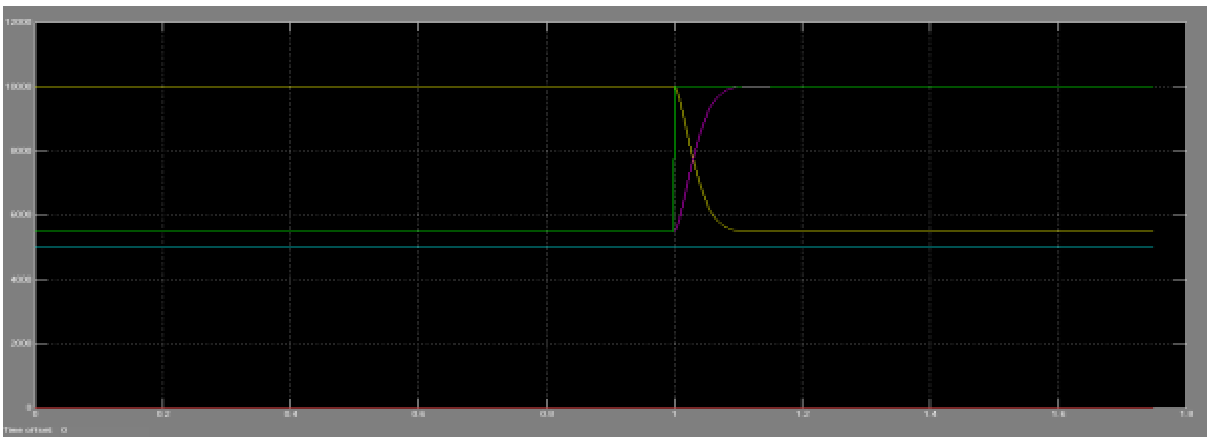
Based on above equations it can be assumed as below. 1) Active power P mainly depends on φ, which is changing by ù. 2) Reactive power Q

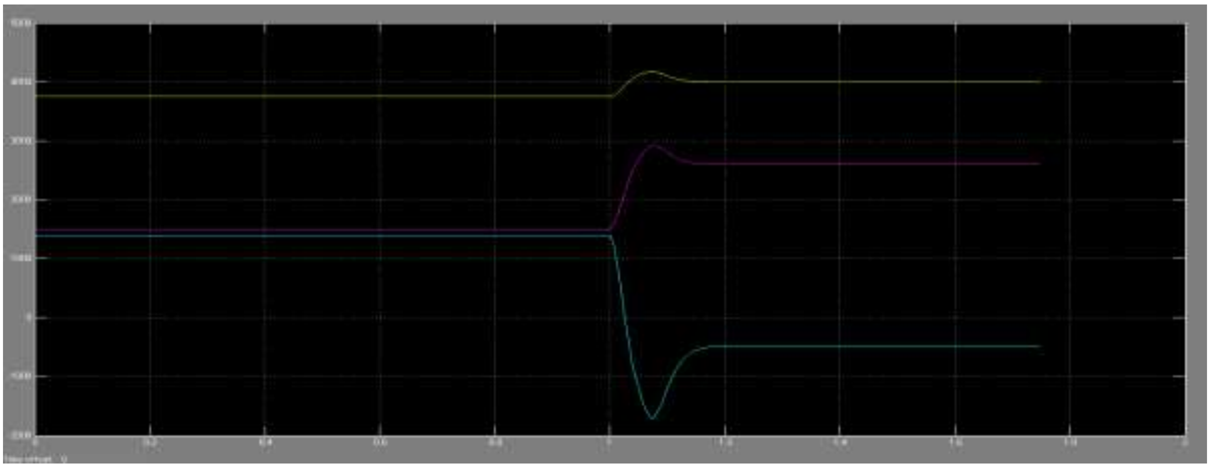
III. PROPORTIONAL REACTIVE POWER SHARING

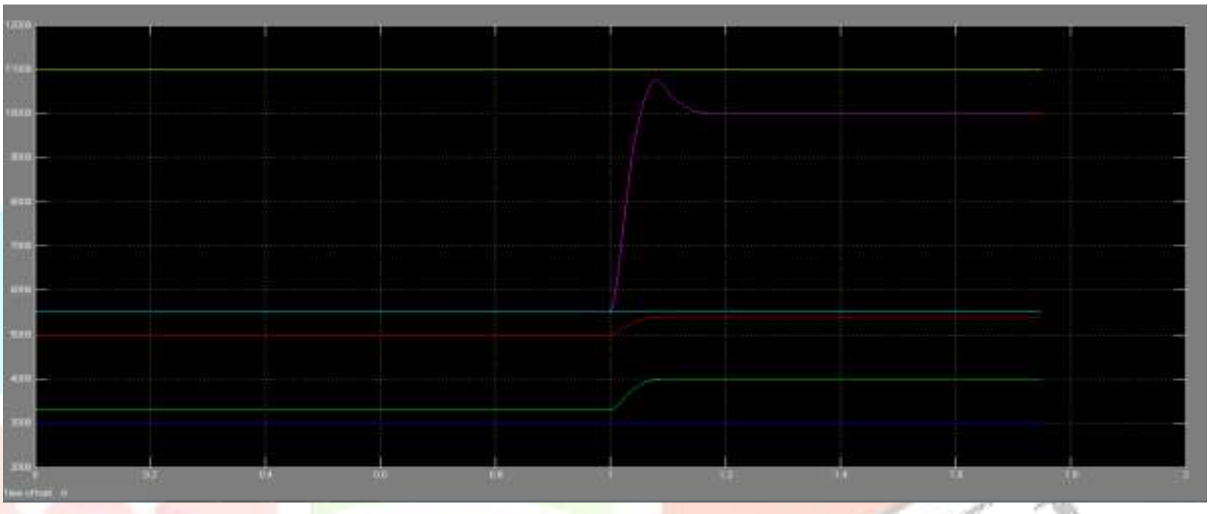
Development of PRPS Algorithm

In order to manage reactive power in islanded ac MG the instantaneous active power and nominal apparent power of each converter have to be taking into consideration. Based on Fryze power theory, that power can be represented by orthogonal vectors, which lengths are active and reactive power and their vector sum is equal to the apparent power. The reactive power limit for each converter can be calculated Qmax = S where Qmax is the maximum of possible converter's reactive power, SN is the nominal apparent power of converter, P is the instantaneous active power of converter.

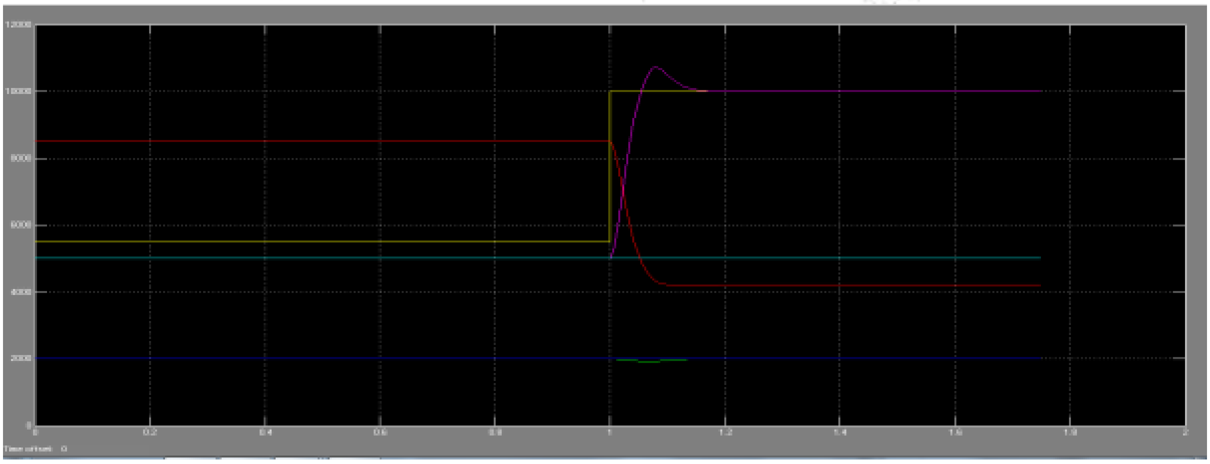
IV. SIMULATION RESULTS:

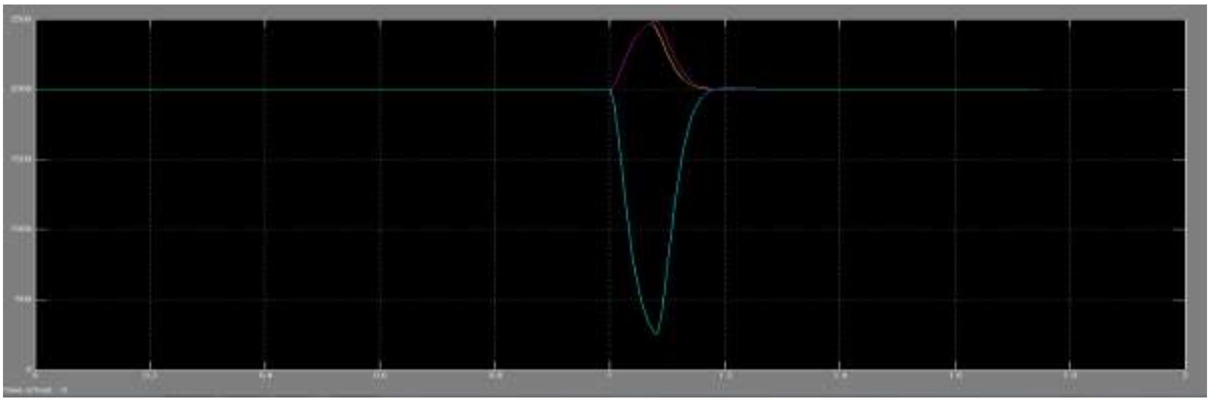


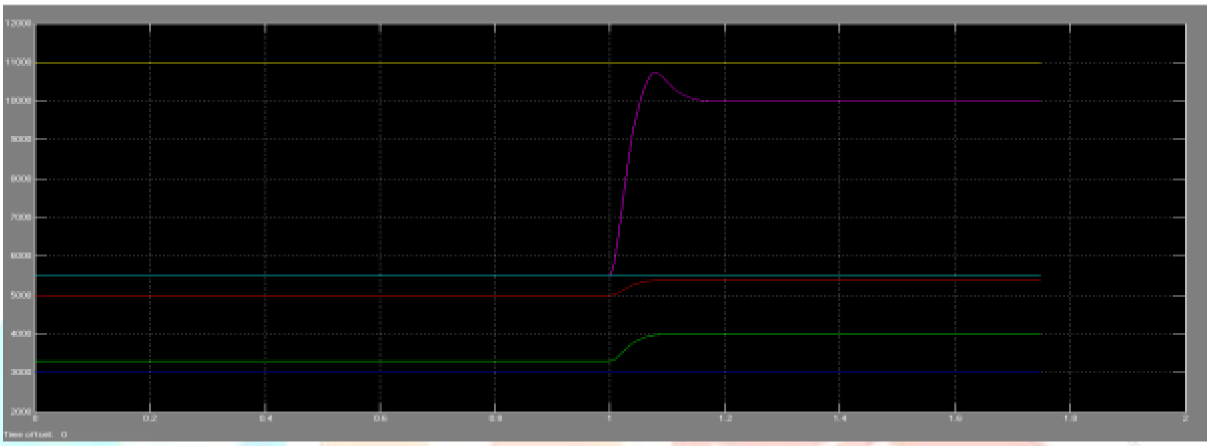




Powers of converters in islanded MG without reactive power management with step change of maximum active power from RESs: *p*1, *p*2, *p*3, *p*storage, converters active powers; *p*_mppt1, *p*_mppt2, *p*_mppt3, maximum active powers calculated from MPPT; *q*1, *q*2, *q*3, converters reactive powers; *S*1, *S*2, *S*3, converters apparent powers; and *S*1, *SN*2, *SN*3, converters nominal apparent powers.







Powers of converters in islanded MG with ERPS with step change of maximum active power from RESs: *p*1, *p*2, *p*3, *s*torage, converters active powers; *p*_mppt1, *p*_mppt2, *p*_mppt3, maximum active powers calculated from MPPT; *q*1, *q*2, *q*3, converters reactive powers; *S*1, *S*2, *S*3, converters apparent powers; and *SN*1, *SN*2, *SN*3, converters nominal apparent powers.

V. CONCLUSION:

MG is the advance system for RES integration with own control structure. Usually the hierarchical control is implemented with droop control in primary level. In islanded mode of operation there is the need to manage reactive power sharing and allow RESs work with maximum active power. Hence, the new reactive power sharing algorithm was proposed in this paper, based on the analysis of power sharing between converters in MG. The novel solution prevents the reactive power circulation and disconnection or damage of any converter in MG. Moreover, it allows to converters operation with MPPT, causing better exploitation of each RES and keeping apparent power of each unit below nominal level as long as possible. Because of short switching period of power electronics converters in RES, the algorithm was developed for implementation in hierarchical control structure, providing parallel calculations in each PCU. Simulation analysis was performed, where the three solutions of power control in islanded MG were compared what confirms the correct operation of developed algorithm and shows the advantage of proportional power sharing over others solution presented in literature.

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