

# ***Integrating Voltage Source Converters (VSCs) into Weak Grids with a Power Damping Controller that Features Self-Synchronization Based on the BATS Echolocation Algorithm***

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## **Abstract**

*In this study, a novel control topology based on the BATS Echolocation Algorithm is utilised to enable successful integration of voltage source converters (VSCs) in weak grids. A linear power-damping and synchronising controller, consisting of two major sections, automatically synchronises a VSC to a grid by supplying damping and synchronising power components, and enables effective full power injection even under very weak grid circumstances. For frequency and angle regulation, the controller employs cascaded angle, frequency, and power loops. The controller simulates the dynamic behaviour of synchronous machines, making grid integration easier and providing a virtual inertia control framework for VSCs to dampen power and frequency oscillations. While the linear controller provides stable and smooth operation in many circumstances, it cannot guarantee system stability in weak grids when big unexpected shocks quickly shift system dynamics to the nonlinear zone. To overcome this complexity, the BATS Echolocation Algorithm-based controller was created to assist the linear controller and improve system performance in the face of large-signal nonlinear disturbances such as self-synchronization, disturbances in grid frequency and angle, high power injection in very weak grids, and fault-ride-through conditions.*

**Keywords:** - Power Damping, DG; VSC; PV Arrays

## INTRODUCTION

Constant advancement of sustainable distributed generation (DG) sources, such as wind turbines and photovoltaic (PV) arrays, has resulted in a significant proclivity toward optimal management, process, and grid integration of DG systems. In the context of smart grids, the seamless integration of DG devices is a crucial driving factor. Voltage source converters (VSCs) are the primary components that enable current technology to interface environmentally favourable and clean energy supplies in modern networks. VSCs' principal control geographies are vector control and direct power control. A phase-locked loop (PLL) is required to obtain current and voltage components in a synchronously rotating reference-frame. In addition, the PLL must calculate grid-frequency and starting angle to provide a smooth converter-grid link via a synchronisation mechanism. Nonetheless, the PLL dynamics during transients have a detrimental impact on overall system security, especially in weak grids. Despite the advantages of vector control, there is a strong trend toward inventing brand-new control regions that do not require a PLL (i.e., self-synchronization). To address issues associated with vector control of VSCs coupled to very weak grids, the power synchronisation concept has been

developed to provide an inherent synchronisation with the grid in steady-state, comparable to a synchronous generator (SG). The proposed solutions are designed for small-signal dynamics and cannot provide large-signal security. The DG link to severely weak grids is one of the testing problems associated with DG integration (high insusceptibility grids). This goal is becoming more important because to the rapid and increasing penetration of off-shore wind turbines and distant PV production devices. Actually, grid stiffness is a stride in the ability of connecting lines to deliver electricity to a grid. Simply said, weak alternating current networks have more difficulty transferring electricity, limiting the maximum amount of accessible power that can be pumped into the grid. The equivalent grid resistance varies over time as a result of errors and tonnes power fluctuation. The short-circuit capability ratio (SCR) is offered as an indication of an ac system toughness compared to the power ranking of a VSC to reflect the strength of air conditioning systems. The inability of vector control to shift rated power in weak grids is a serious disadvantage. Only 40% of a VSC's optimum power capability can be utilised on a poor grid with SCR. This percentage may be increased to 60% with significant altering initiative of the vector controller

criteria and the PLL. The notion of power synchronisation control presented as an option, thus appropriate to allow higher power transfer by a VSC by reproducing SGs. Because SGs have no limits for linking to weak systems, control approaches such as power synchronisation that mimic SG features can easily allow VSCs to be combined in extremely weak grids. However, the suggested solutions for weak grid combination are based on linearized models and lack self-synchronization as well as plug-and-play capability. The islanding of DG units might be authorised to improve solution reliability. Regularity droop is a common technique for power monitoring in the islanded procedure of VSCs; nevertheless, this approach results in a long-term frequency balanced out. When self-synchronization control is applied, a frequency and angle mismatch between a VSC and the grid current of connection may create significant transients. Another key difficulty with VSC operation in weak grids is the lack of physical inertia in traditional VSCs, which results in poor overall regularity and tonnes angle policy; hence, islanded process of mini grids (MGs) with high VSC penetration might be prone to regularity instability. As a result, major efforts have lately been focused to presenting some features for regularity via

digital inertia. Typically, digital inertia refers to a VSC's addition of short-term energy storage. In this case, appropriate dc-link control imitates digital inertia. In response to the aforementioned challenges, this work proposes a crossbreed nonlinear control of VSCs in weak grids. The controller incorporates a power synchronisation loophole, as well as other plunging damping and integrating loopholes. The key characteristics of the suggested controller are summarised as follows: 1) The crossbreed nonlinear power damping controller enables VSC self-synchronization in weak grids. This implies that the controller does not require a separate synchronisation device and that it synchronises itself with the grid automatically. Self-synchronization is a novel concept, and its importance is amplified in weak grids. It should be noted that the process still requires the start time of synchronisation and certain information from the distant grid, so it cannot identify a true plug-and-play method. Furthermore, its performance and security in weak grids have not been investigated. It is obvious that during islanding, an MG may typically experience irreversible regularity decrease representing significant regularity as well as angle inequality at the time of reconnection; however, the proposed controller system does not require any

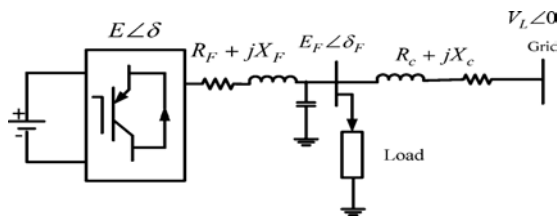
initial synchronisation with the grid and recognises a plug-and-play system. The fundamentals of plug-and-play as well as nonlinear self-synchronization in VSCs are given for the first time. 2) The controller has frequency, power, and angle loops. It is possible to get a higher security margin as well as dampening properties. This is an expansion of, in which the notion of participation droop was proposed. Nonetheless, the system demanded precise load angle adjustment and true power references, and it also lacked voltage policy. This problem is addressed in this study by employing a regularity loophole as a first controller; hence, the frequency reference is readily made equivalent to the grid nominal regularity. 3) Because the controller operates in a dynamic manner similar to classic SGs, it may be connected to extremely weak grids with SCR without compromising security. 4) A nonlinear additional controller is designed to provide system security in all operating conditions, particularly when the lot angle wanders into the nonlinear area. 5) Because the controller is applicable to both grid-connected and islanded modes of operation, the necessity for islanding detection and system reconfiguration is eliminated immediately. 6) It provides fault-ride-through capability by properly adjusting frequency, tonnes angle, and voltage

amplitude, resulting in restricting current streaming directly into the interface circuit. It also tracks and dampens large grid outages in real time. The proposed control topology is broad in the sense that it may be immediately coupled to VSC-based HVDC transmission systems and DG systems; nevertheless, the major focus of this research is on DG applications.

To overcome troubles connected with vector control of VSCs connected to very weak grids, the principle of power synchronization has actually been offered to provide an integral synchronization with grid in steady-state comparable to a concurrent generator (SG). Among challenging problems dealing with DG assimilation is the DG link to very weak grids (high insusceptibility grids).

The grid stiffness is a procedure of the connecting line ability to transfer power to a grid. In other words, weak air conditioning grids encounter more problem for power flow transfer, therefore the maximum quantity of readily available power that can be infused to the grid is a lot more restricted. One more significant issue related to VSC operation in weak grids is the lack of physical inertia in standard VSCs resulting in inadequate total frequency as well as load angle regulation;

hence, islanded procedure of micro grids (MGs) with high infiltration of VSCs can be prone to frequency instability.



**Fig: 1 Circuit Diagram of Grid connected VSC**

### BATS ECHOLOCATION ALGORITHM

The Bat calculation is a metaheuristic calculation for worldwide advancement. It was enlivened by the echolocation conduct of microbats, with fluctuating heartbeat rates of outflow and loudness.[1][2] The Bat calculation was produced by Xin-She Yang in 2010.

The romanticizing of the echolocation of microbats can be compressed as takes after: Each virtual bat flies haphazardly with a speed  $v_i$  at position (arrangement)  $x_i$  with a fluctuating recurrence or wavelength and  $A_i$ . As it hunts and discovers its prey, it changes recurrence, tumult and heartbeat discharge rate  $r$ . Hunt is heightened by a neighborhood irregular walk. Determination of the best proceeds until the point when certain stop

criteria are met. This basically utilizes a recurrence tuning procedure to control the dynamic conduct of a swarm of bats, and the harmony amongst investigation and abuse can be controlled by tuning calculation subordinate parameters in bat calculation.

A nitty gritty presentation of metaheuristic calculations including the bat calculation is given by Yang [4] where a demo program in Matlab/Octave is accessible, while a far reaching survey is done by Parpinelli and Lopes.[5] A further change is the improvement of a developing bat calculation (EBA) with better proficiency.[6]

### PROPOSED LINEAR CONTROL TOPOLOGY

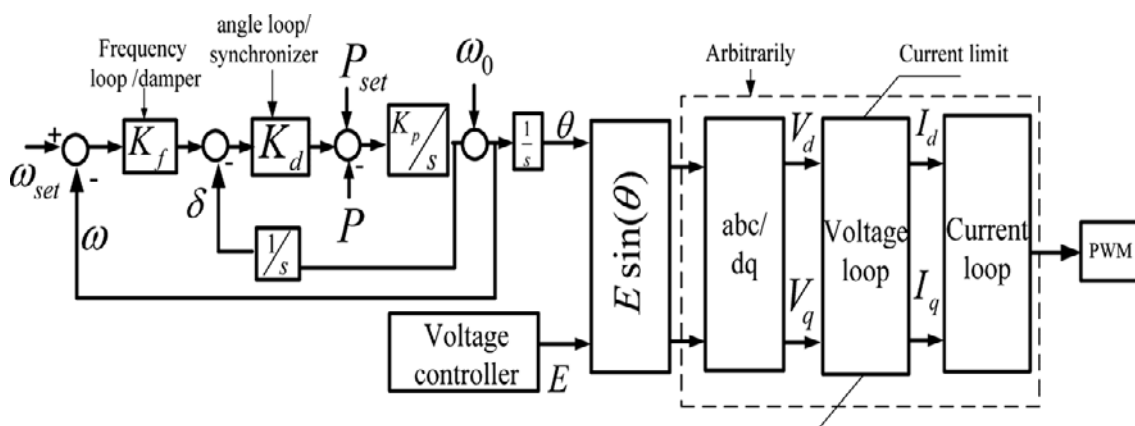
This paper focuses on the development of a nonlinear power damping control strategy for VSC units in weak grids with applicability to both grid-connected and islanded modes of Operation. Fig-2 shows the schematic view of a grid-connected VSC supplying a local load. The most critical issue for controller design is the complexity of the system due to nonlinear behavior of the power transfer dynamics. Usually, linear controllers are developed based on small-signal linearization; however, the control performance

inherently depends on specific operating points. In this paper, a two-level topology with cooperative nonlinear and linear controllers is developed. The first level is a power synchronizing-damping controller. The second level is a nonlinear controller supporting the linear part to enhance system stability in weak grids or during self-synchronization where load angle is large and system works in the nonlinear region.

The voltage generation principle is similar to an SG where the voltage frequency and load angle are tuned by power damping-synchronizing loop, whereas the voltage amplitude is given by voltage regulation loop similar to an automatic voltage regulator (AVR). The VSC's output real power is controlled directly by adjusting

the load angle using the power-damping loop, whereas the reactive power (or alternating voltage) is controlled by adjusting the voltage magnitude. Since the VSC is voltage-controlled one, an inner current loop is not necessary except during large transients such as faults where the control strategy should be changed to current control mode to limit the current amplitude.

It should be noted that the proposed outer-loop controller can be also integrated with cascaded voltage-current control loops to ensure high power quality injection and inherent current limitation during faults. In this case, the synchronization angle for dq-frame transformation is obtained from the proposed outer-loop controller instead of a PLL.

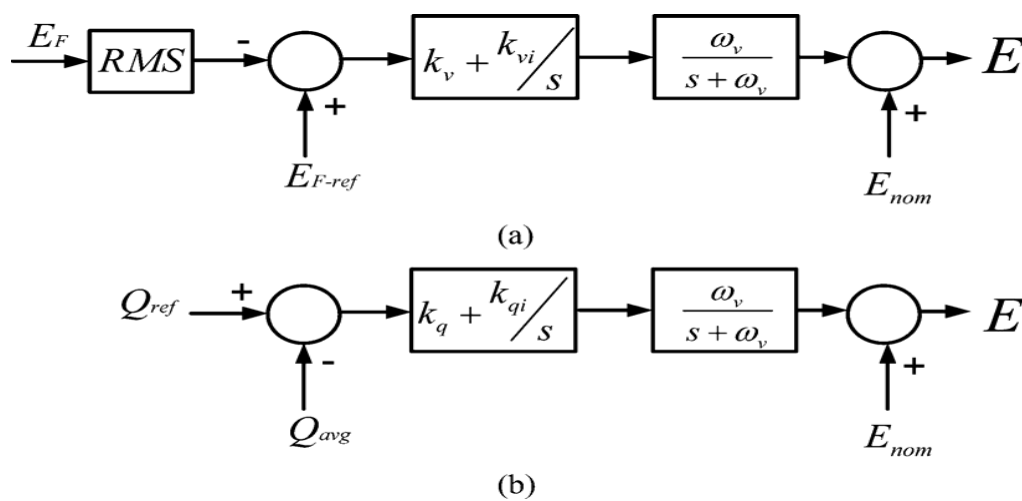


**Fig: 2 Linear Control Scheme**

### A. Power Damping/Synchronization Control Concept:

The base of power damping control of a grid-connected VSC is that the controller provides active damping and synchronization power to attenuate power, frequency and load angle oscillations, and synchronize the VSC with the grid during steady-state operation. By changing the control strategy of VSCs to comply with the power damping characteristics, VSCs can be integrated to weak grids and also cooperate with SGs in power grids. Fig.2.1. demonstrates the basic principle of the proposed controller in the polar system. It has three cascaded loops, namely frequency, angle and power loops. Based on the frequency error, the reference of the load angle is determined and the real power reference is obtained as a function of the

load angle error. Finally, the power synchronization loop adjusts VSC's instantaneous frequency and load angle. The angle and frequency loops generate synchronization and damping power components for the VSC, thus it can inherently track frequency and angle deviations of the grid and automatically synchronizes itself with the grid. The reference frequency in the frequency loop is set equal to the grid frequency, and in steady-state conditions, the VSC produces the reference power. This can be the case in dispatch able DG units or VSC-based HVDC transmission systems. In the case when the primary source falls short to supply the output power, short-term energy storage can be added to the dc-link to compensate for the energy shortage during transients.



**Fig. 3 Control topologies for output voltage control. (a) P-V bus control. (b) P-Q bus control strategy**

## SYSTEM MODELING

To evaluate system dynamic performance in a weak grid, a small-signal stability analysis of a grid-connected VSC is presented in this section. The three-phase power system involves a converter and its controller, RL filter, connecting line and infinite grid.

Assuming an ideal VSC, the VSC local voltage is equal to the controller command, thus it is possible to model the VSC and PWM block by an average voltage approach. The system parameters are given in Table I.

The augmented model of the VSC and its controller can be developed as follows. First, the load angle dynamic equation is given by

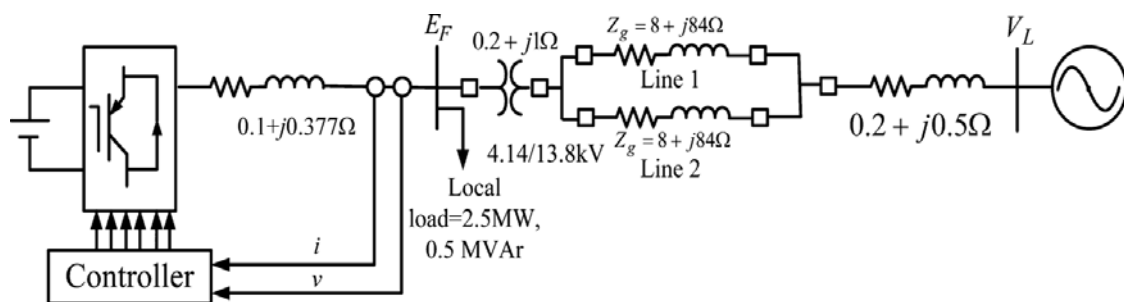
$$\Delta \dot{\delta} = \Delta \omega.$$

## SIMULATION RESULTS

**Fig. 4** shows the configuration of the simulated system. The system is composed of a 7.0 MW VSC, filter, local load, transformer and an interface line connecting the VSC to a grid. It is worth to mention that the impedance is the equivalent impedance of the stiff source referred to the distribution level.

The simulation study was conducted in MATLAB/SIMULINK environment. The DG unit supplies the local load at its output terminal and is connected to a stiff grid through a very weak interface with total impedance of.

Since the connecting line is almost inductive, the power capacity of the interface line is approximated by (31) where the notations are defined in Fig.3 and is the total reactance of the transformer, line and stiff grid.

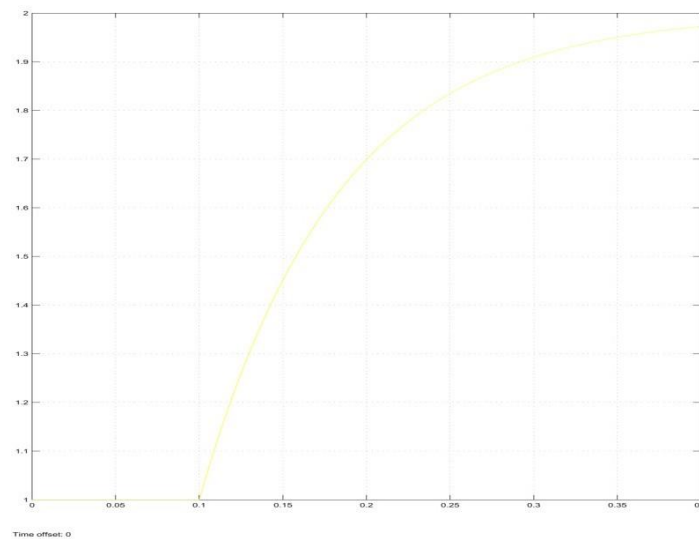


**Fig: 4 Simulated Systems**

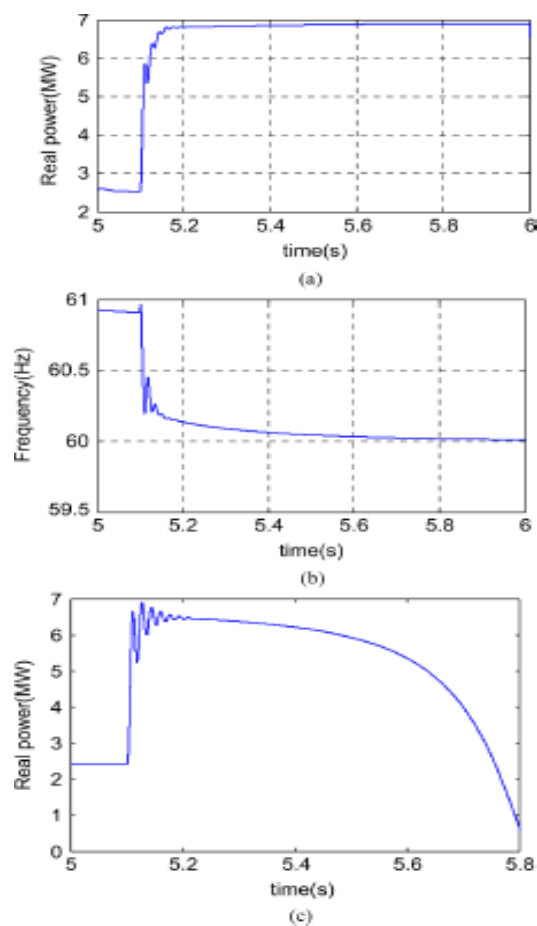
Therefore, the maximum real power transfer capacity of the connecting line is equal MW. Since the local load power at the rated voltage is 2.5 MW, thus the VSC's maximum power capacity is about 7 MW. The DG works as a PV bus aiming at keeping the filter output voltage constant during grid connection. A wide variety of scenarios have been applied to verify the effectiveness of the proposed hybrid nonlinear controller. System performance at low- and high-power references, transition to islanding, self-synchronization, sudden deviation in grid angle and three phase fault is studied. The advantage of the proposed controller is its flexibility to work in different conditions, i.e., grid-connected and islanded modes without reconfiguration whereas the nonlinear grid synchronizer enables the plug-and-play fig

The following results can be retained from the simulation results: from sections (a) and (b) it is drawn that the controller is able to function in both low-power and high-power levels in very weak grids. The SCR of the system is equal to one and as it will be shown that the VSC can easily inject 0.85 p.u. real power to the grid while it has well-damped transient performance. This is in contrast with conventional vector control which can only exchange 0.6 p.u. real

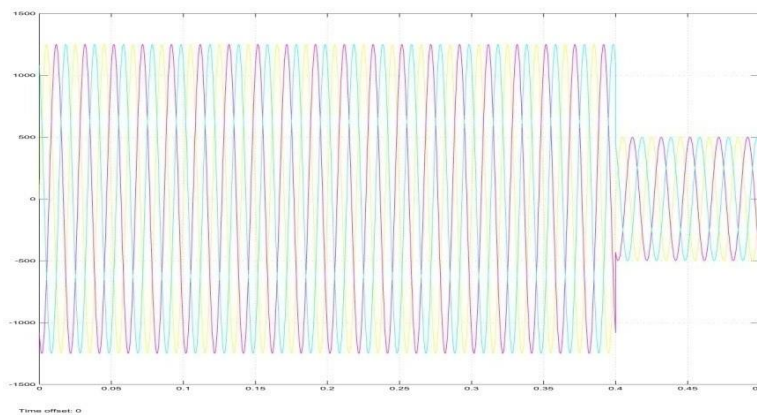
power with a grid; otherwise it might face instability. As will be shown in subsection C, the controller presents very smooth transition to the islanded mode although there is no any islanding detection process and the controller's configuration and parameters are not changed. The self-synchronization ability of the controller will be presented in subsection D where the re-closer is suddenly closed and the VSC is connected to the grid without a pre-synchronization process which is mandatory in conventional controllers. In this case, the supplementary nonlinear controller preserves the self-synchronization capability with large-signal stability. The controller without supplementary nonlinear control cannot offer self-synchronization capability under large-signal disturbances. Fault-ride-through is another advantage of the proposed controller and it will be shown that although the VSC works as a P-V bus, the current flowing in the power circuit during a three-phase fault is limited because of proper load angle adjustment. Moreover, because of its damping and synchronizing powers, it has the ability to work as a virtual PLL and tracks grid's angle and frequency variation as presented in subsection E.



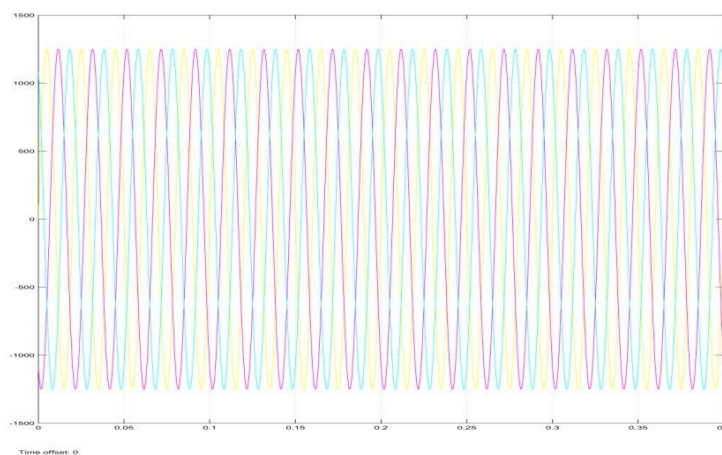
**Fig: 5 Controller Performance in Low-power injection**



**Fig: 6 System performance during grid restoration, (a) Real power with nonlinear supplementary controller. (b) Frequency. (c) Real power without the supplementary controller**



***Fig: 7 Instantaneous current waveforms subsequent to a three-phase Fault***



***Fig: 8 Instantaneous current waveforms subsequent to reconnection of line 2.***

## CONCLUSION

A novel BATS control architecture is given in this study to enable successful integration of VSCs to weak grids. The controller is divided into two sections: the linear power damping controller and the nonlinear supplemental controller.

The linear component replicates SGs with additional power damping-synchronization capacity, allowing self-synchronization with the grid and eliminating the

requirement for a PLL. In grid restoration settings, however, any significant mismatch between VSC and grid frequency and angle may result in poor performance and even instability. Because there are large-signal disruptions, the suggested nonlinear controller can improve system performance in certain instances.

Furthermore, due to its damping and synchronising power characteristics, the controller may function in very weak grids

with SCR and supply the rated power. The design approach for linear and nonlinear sections was described, as well as several simulation scenarios to test the controller efficacy.

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