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Overview of Hysteresis Current Controller Application in Renewable Energy Based Power Systems

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Abstract. This paper presents an overview of the Hysteresis Current Controller (HCC) application in Renewable Energy Based Power System. The beginning concept of HCC is considered to be formally introduced by Thomas M. Freederiksen and Ronald W. Russel in 1971 that was registered in US Patent No. US3725673. The fundamental principle of HCC is based on the comparison of the instantaneous load current to the instantaneous sine wave reference where the difference between the two is maintained within the defined upper and lower band. There are some advantages of using HCC including simple, insensitivity to load parameters variations, fast dynamic response and inherent maximum current limiting characteristics. Therefore, based on its robustness, HCC has currently applied also in renewable energy based power plants such as PV converter system, Power Electronics System of Wind Energy, and in SMES control system for Wind Energy Application. However, the drawback of HCC system was also discussed in some papers compared with other control systems, for instant HCC is giving high chattering in torque in IM drive test. Therefore the combination of HCC with other controllers also becomes a new trend to improve the applied system that involving HCC as the main controller.

1. Introduction

The beginning concept of HCC is thought to be formally introduced by Thomas M. Freederiksen and Ronald W. Russel in 1971 that was registered in US Patent No. US3725673 [1]. Since that many researcher were attracted to develop the HCC and applied in many power electronics applications. The fundamental principle of HCC is based on the comparison of the instantaneous load current to the instantaneous sine wave reference where the difference between the two is maintained within defined upper and lower band [2]. A current controller is basically applied to follow the current command of an apparatus such as motor drive, UPS, active filter, etc [3]-[6]. Due to the advanced technology improvement of power electronics, current controller techniques have become popular over the last decades as proposed in [7]-[18]. Moreover, due to simplicity, insensitivity to load parameters variations,

fast dynamic response and inherent maximum current limiting characteristics [19], hysteresis current control (HCC) is a rather popular one. The fundamental operation of HCC is based on performing the switching signals simply by comparing the actual phase current with a determined tolerance band that is following the reference current with its phase. However, this band control scheme is affected by all three phases not solely by the associated phase only [20].

Typical HCC with its switching responses can be seen in Fig. 1 and 2 respectively.
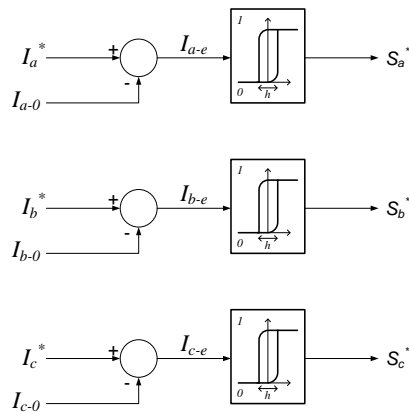
Figure 1. Three-phase hysteresis current control method [21]
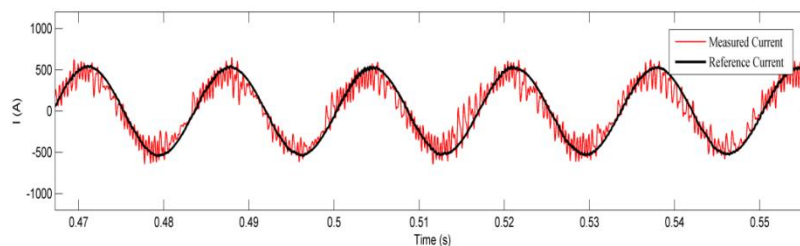
Figure 2. Typical hysteresis current [21]
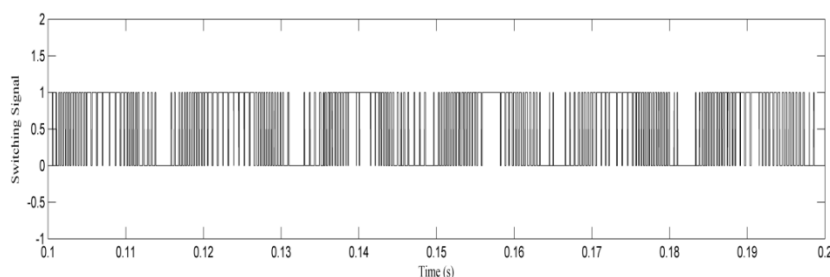
Figure 3. Typical switching response for hystersis current [21]

The effect of interference between phases (referred to as inter-phases dependency) can lead to high switching frequencies. In order to keep the advantages of HCC methods, a phase-locked loop (PLL) is applied to reduce the phase dependency and to maintain the converter switching at its fixed frequency setting level [22].

2. HCC Robustness and Drawbacks

2.1. Robustness and Prominent of HCC

As aforementioned above that HCC is become popular due to its simplicity, independently from rapid load change, dynamic response and inherent maximum current limiting characteristics [19]. Moreover, as mentioned in [23], HCC is the most commonly used technique based on its applicability on nonlinear control techniques, low software requirements, high reliability, and less tracking error. It is proven also in [23] that HCC gives faster response compared to SVPWM techniques whether in no load or with the load for the IM drive test.

### 2.2. Drawbacks Compare to Other Control Algorithm

Although HCC has several advantages compared to other controls, there are some drawbacks of this control method for instants; HCC is giving high chattering in torque in IM drive test [23] and compare to HCC, SVPWM is more suitable for power control of PMSG and also giving better energy dispatch to the grid due to the lower DC link voltage and better reduction of harmonics content of SVPWM [24].

## 3. HCC Application in Renewable Based Power System

Based on its prominent and advantages, there are many papers introducing the application of HCC in renewable energy based power systems as discussed in [25]-[38].

The booming of renewable energy based power plants implementation such as solar cell (PV) and wind turbine system is not separated from the revolutionary of power electronics devices. The involvement of HCC in the solar power system can be found in many papers, for example in [25], D-STATCOM based on HCC is applied to stabilize the voltage profile of connected PV power plants with the distribution system. In this paper, three common faults condition of voltage sag, voltage swell and short circuit were applied. A method of extracting maximum power from PVs-grid connected using phase angle control and HCC is proposed in [26], where the applied method could not only extracting maximum power from the PVs but also could maintain the THD within the standard of IEEE. The application of HCC that is combined with ANN in determining the MPPT (Maximum Power Point Tracking) of PV is proposed in [27] and drawn conclusion that the proposed maximum power point tracking control using neural networks maintains accurately the maximum power and shows fast dynamic response against sudden environmental condition changes or disturbances.

Simulation of three levels HCC that employed on four-leg VSI is proposed in [28], the simulation results justify the performance of VSI as a power injector as well as a power conditioner for compensating current harmonics, reactive power, neutral current and current imbalance. D Bini and J.C. Paul in [29] have introduced PV generation with Γ-Z source inverter that supplies AC load for a standalone system.
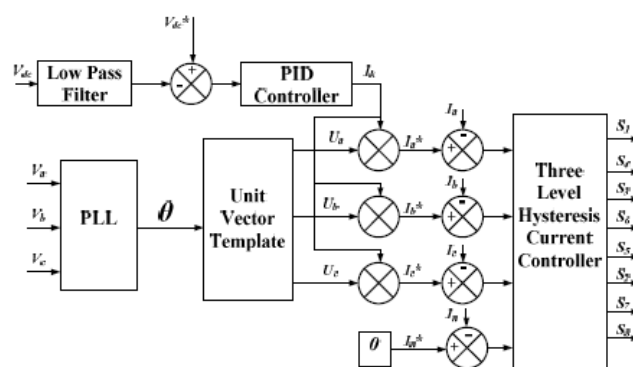
**Figure 4.** Block diagram of grid connected VSI control with 4 legs [28]
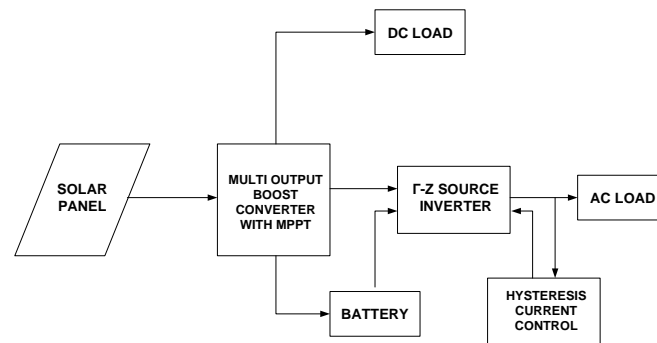
Figure 5. Block Diagram system of PV that applied HCC with T-Z source inverter for supplying AC loads [29]

A proposed formulation of the unified time domain of switching frequency of converters that are connected to a grid is presented in [30]. The formulation is obtained from the general expression of the switching frequency that used to apply for any mode of operation of a converter that is based on the relationship between the reference AC current and the grid voltage. In [30], three single phases of the current control mode are presented in this paper including static synchronous compensator, boost rectifier and grid interface PMSG based wind turbine generator.

The three levels HCC exhibits reduced switching frequency, dynamic control capability, and easy implementation. Adaptive HCC for DGs grid connected is also discussed in [31]. The main purpose of the proposed control algorithm in [31] is intended to allow the output of inverter resistant to the fluctuations in the DC input voltage. This kind of inverter is suitable for small to medium scale wind turbines and PV cells to the grid and possible to compensate connected reactive power load.

Application of HCC on wind turbine generator is presented in many papers. As current popular wind turbines are equipped with power electronics such as Doubly Fed Induction Generator (DFIG) and Full Converter Wind Turbine Generator (FCWTG) or so-called type 4 WTG, HCC becomes applicable for wind turbine power electronics system. In [32], the new vector control of DFIG that is based on HCC is proposed. In [32], synchronization of the proposed control scheme with the virtual grid-flux space vector that is extracted by the quadrature phase-locked loop (QPLL) system. The proposed Identical equidistant-band vector-based hysteresis current regulators (VBHCRs) are then applied to regulate the output currents for both rotor-side and grid-side converters. Implementation of HCC on Superconducting Magnetic Energy Storage (SMES) that is connected to the DFIG is proposed in [33]. The proposed system of SMES Unit with HCC is depicted in Fig. 6.
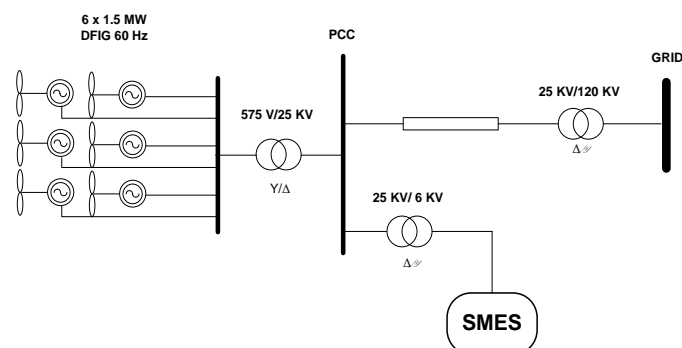

Figure 6. DFIG Connected with the grid and equipped with HCC Based SMES at PCC [33]

In Fig. 6, SMES Unit that is connected at PCC of the DFIG-Grid connected is controlled in two control algorithm scheme as shown in Fig. 7. [33]. The VSI is controlled with HCC where the DC-DC

converter that dictates the charging/discharging energy from the SMES' coil is controlled with the Fuzzy Logic Controller. The application of HCC in SMES Unit have been proposed in many functions such as in improving voltage profile at PCC during voltage sag [33] and swell [34], short load variation [35] and converter faults [36],[37]. Its application on Type 4 WTG is also discussed in [38] for short circuit. Comparison responses and performances of DFIG and Type 4 WTG that is equipped with HCC based SMES is also presented in [39]. A study comparison of HCC based SMES with D-STATCOM during faults at Type 4 WTG is detailed discussed in [40]. The results of the comparison show that HCC-SMES could improve the performance of the wind turbine particularly for correcting voltage profiles at PCC compare to D-STATCOM.
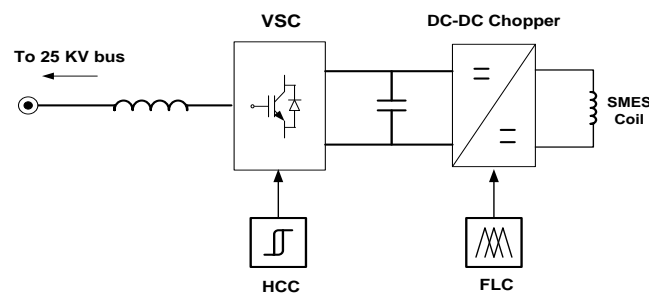
Figure 7. SMES control configuration with HCC and Fuzzy Logic Controller [33]
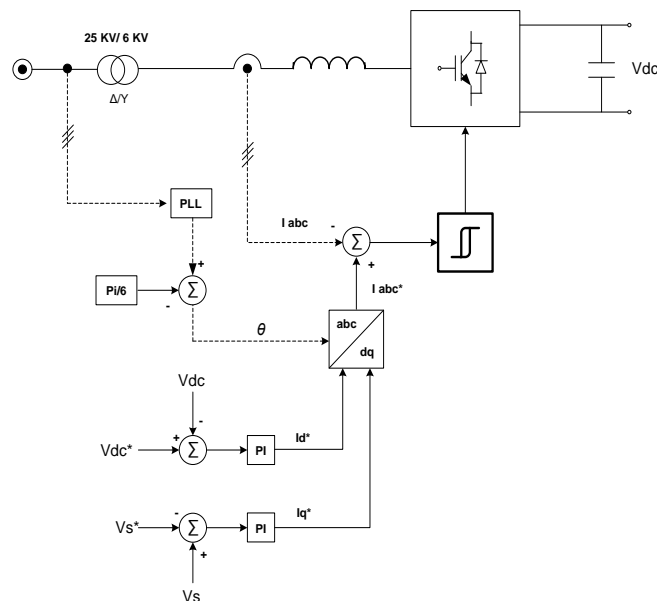
Figure 8. Detailed control VSI with HCC [34]

4. Conclusion

Overview of Hysteresis Current Controls (HCC) on Renewable Energy Based Power System has been discussed in this paper. Based on its benefits including fast response, independency on load current variation, simplicity and easiness implementation has brought it to be widely implemented in PV, Wind, and SMES-Based WTG applications. Most of the literature proposed the technical system of HCC using simulation and/or with practical measurements. Based on the overview HCC and its development such as combination with vector control and fuzzy logic, HCC is still become a promising control system and

open the opportunity in the near future for application on power electronics that equipped in renewable energy based power systems.

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