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THE STABILITY OF A DC DISTRIBUTION SYSTEM THAT INTEGRATES PLUG-IN HYBRID ELECTRIC VEHICLES (PHEVS) WITH AN AC POWER GRID

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ABSTRACT

This project proposes a method for enhancing the stability of a dc distribution system that integrates plug-in hybrid electric vehicles (PHEVs) with an ac power grid. The dc distribution system is interfaced with the host ac grid via a voltage-sourced converter and can also embed photovoltaic (PV) modules. Thus, bidirectional dc–dc electronic power converters act as battery chargers and interface the PHEVs with the dc distribution system, while DC Link modules are interfaced with the dc distribution system via unidirectional dc–dc converters. The dc distribution system is expected to be more efficient and economical than a system of ac–dc battery chargers directly interfaced with an ac grid, but it is prone to instabilities due to the constant-power property of the dc–dc converters. Using a nonlinear control strategy, the proposed stability enhancement method mitigates the issue of instability by altering the power set points of the battery chargers, bidirectional dc–dc converters, without a need for changing system. The project presents mathematical models for the original and modified systems and demonstrates that the proposed technique expands the stable operating region of the dc distribution system.

INTRODUCTION

The outlook of a large number of electric vehicles, including plug-in hybrid electric vehicles (PHEVs), and their potential impacts on the power system have motivated much research recently. The U.S. Department of Energy projects that more than about one million PHEVs will have been sold in the U.S. by 2015 and the current incentives by the U.S. government will promote and increase the sales of PHEVs. In public parking areas where a sizable number of PHEVs are interfaced with the power grid, such ancillary services as the provision of back-up power for commercial facilities, voltage support, frequency regulation, peak shaving, reactive-power support [6], and integration of photovoltaic (PV) panels can be offered by PHEV batteries. To provide such services, bidirectional battery chargers must be employed to enable energy exchange between PHEVs and the host grid. In most proposed integration strategies, ac–dc power electronic converters act as the battery chargers and are directly interfaced with the power grid As a perceived technically and economically superior alternative, dc distribution systems have recently been proposed in which dc–dc converters act as the battery charges, especially for public areas.

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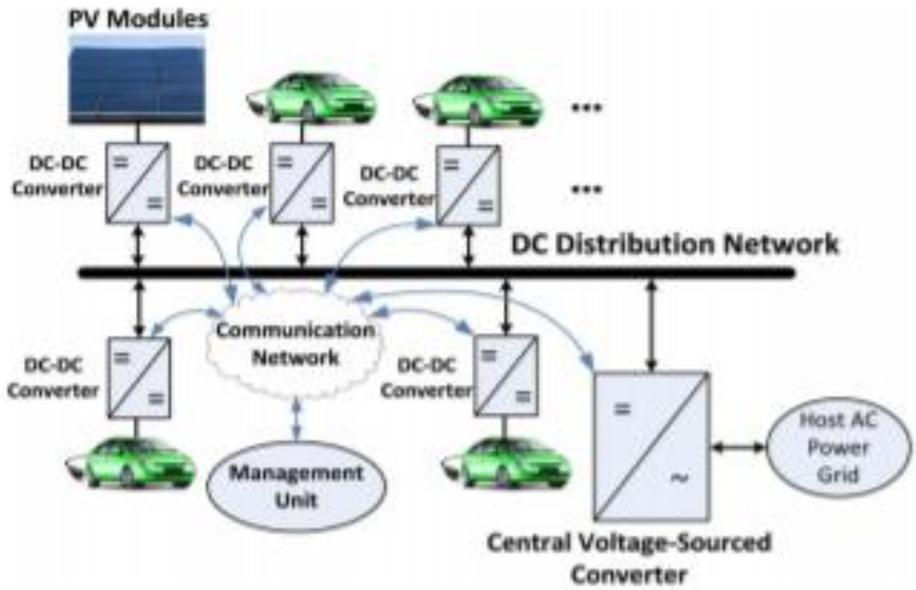

Fig. 1. dc bus for distribution of power in a parking lot for PHEVs.

A dc distribution system can more efficiently host PV modules and interfaced with the power grid via a central ac–dc power-electronic converter. However, due to the constant-power property of dc–dc converters, it becomes unstable if the powers absorbed by the battery chargers exceed certain values [13]. This phenomenon inflicts a limit on the maximum power that can be imported to charge the batteries and, consequently, precludes full utilization of the installed capacities and prolongs the charging times. Therefore, it is imperative to: 1) systematically characterize the phenomenon and identify the prevailing constraints; 2) devise a stability enhancement technique, in order to push the limits and expand the stable operating region of the dc system. To mitigate the aforementioned issue of instabilities caused by constant-power elements in a dc distribution system, various methods have been proposed in the literature, [17]–[19].

PROPOSED SYSTEM CONFIGURATION

The method proposed in [17] stabilizes a dc-link electric propulsion system where a dc–ac converter drives an induction motor, by altering the torque setpoint of the motor. The proposed technique, therefore, is applied to a dc system with one constantpower element; there is no analysis for multiple constant-power elements. The techniques proposed in [18] and [19] deal with a system in which a dc–dc converter is assumed to be supplying another constant-power element. However, both techniques require information about the internal state variables and access to the pulse width modulation (PWM) signal of the dc–dc converter. Moreover, the studied systems include only one dc–dc converter and one constant-load element. Expanding upon the idea proposed in [17], this paper proposes a control technique for expanding the stable operating region of a dc distribution system integrating PHEVs via bidirectional dc–dc converters (battery chargers), such that the dc system and its PHEVs can import larger powers from the host ac grid. The proposed technique is simple, does not require information internal to the system or its embedded converters, and does not need hardware modifications. Rather, it only employs local measurements and individual power setpoints and, therefore, can be exercised in a decentralized fashion. These, in turn,

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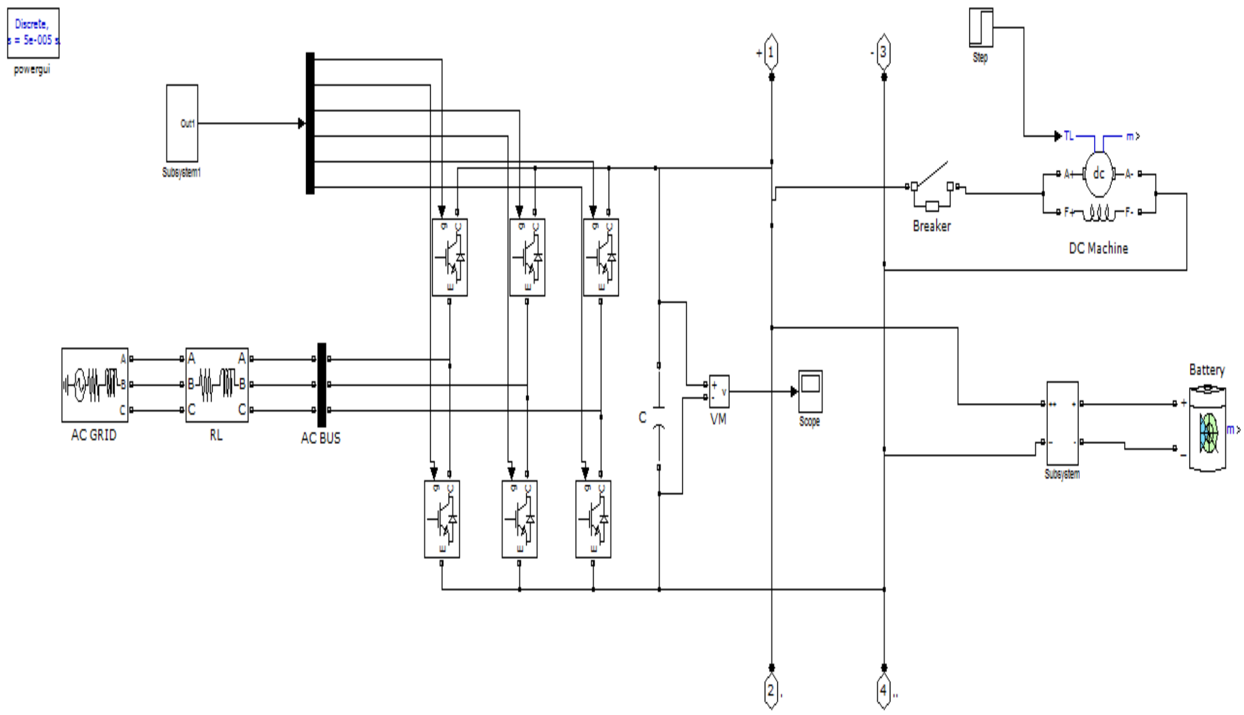
permit the use of commercially available dc–dc converters (battery chargers), expected to further reduce the overall cost of the system. The proposed technique is also applicable to other dc distribution systems, e.g., shipboard power systems, that have multiple power-electronic converters 1 illustrates a dc distribution system, for example, in a parking lot, that hosts PHEVs and PV modules. In this system, dc–dc converters are utilized as battery chargers for the PHEVs and also for interfacing the PV modules. Moreover, a central voltage-sourced converter (VSC) interfaces the dc distribution system to the host ac grid. A communication network [20] is used to enable the exchange of metering and control information for a management unit, to and from the dc–dc converters and the central VSC. The management unit calculates the limits of the power exchange setpoints and sends them to the dc–dc converters, to ensure that the dc system operates in its stable operation region. The PHEV owners, on the other hand, can set state-of-charge (SoC) limits for their vehicles, to permit power exchanges only if the SoC resides within a certain range. For example, if the SoC is above 70%, then energy can be sold to the rest of the system, whereas if the SoC is below 40%, then the vehicle should buy energy from the rest of the system. The aforementioned limits (determined based on the trip plans, electricity price, and other factors) translate into power setpoints for the corresponding dc–dc converters. For example, for a PHEV with 20 kWh of battery capacity, if the SoC limit for energy export is 70% and the present SoC is 85%, then 3 kWh (that is, 15% of the battery capacity) can be sold by the PHEV to the rest of the system, meaning that the power setpoint of this particular PHEV can be set to export 9 kW of power in 20 min, or 3 kW of power in 1 h, and so on



PROPOSED CIRCUIT CONFIGURATION WITHOUT COMPENSATION

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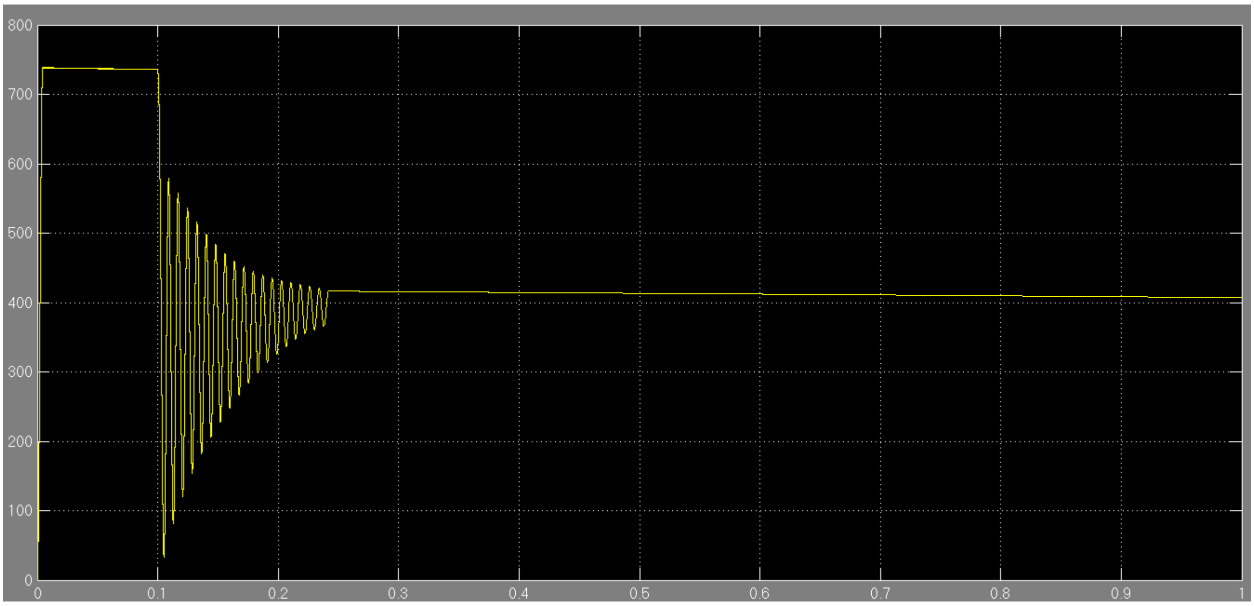
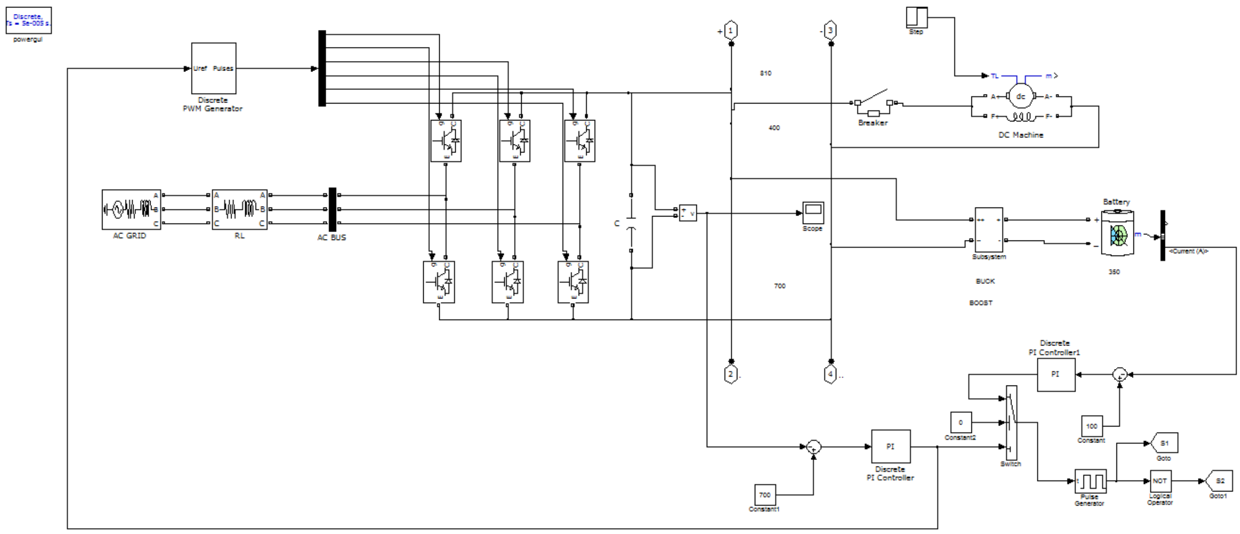


FIG DC LINK VOLTAGE WITHOUT ANY COMPENSATION



PROPOSED CIRCUIT CONFIGURATION WITH CURRENT CHARGING METHOD

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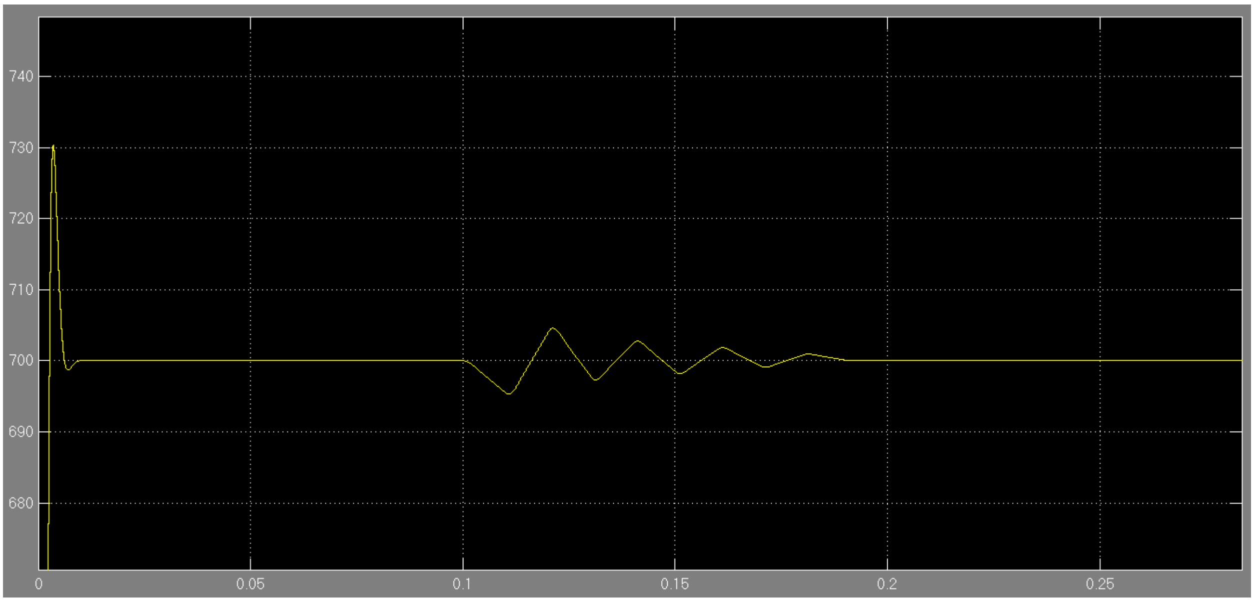
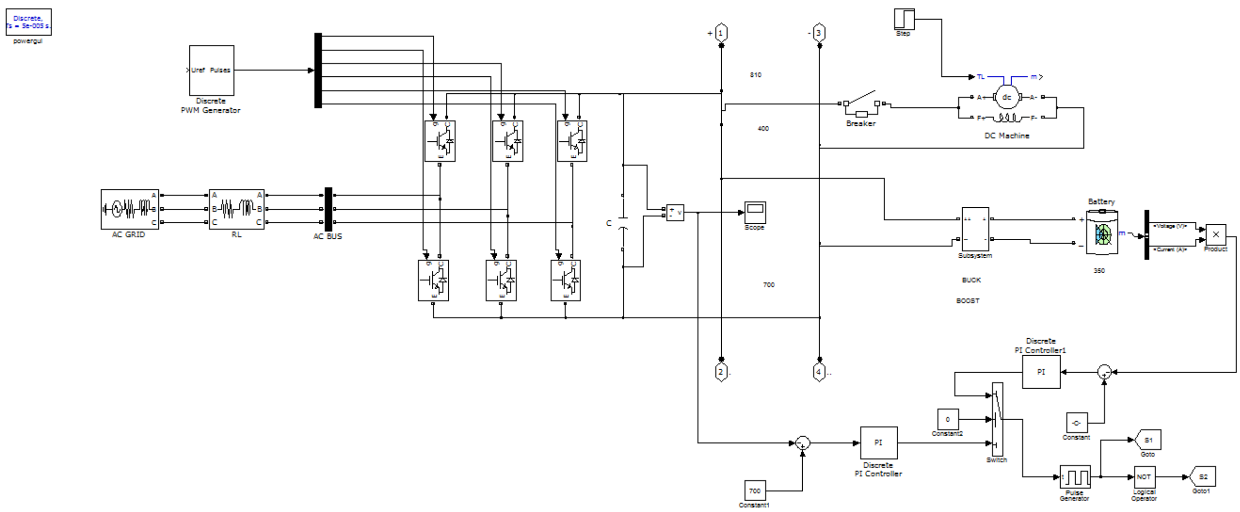


DC LINK VOLTAGE WITH CURRENT CHARGING METHOD



PROPOSED CIRCUIT CONFIGURATION WITH POWER CHARGING METHOD

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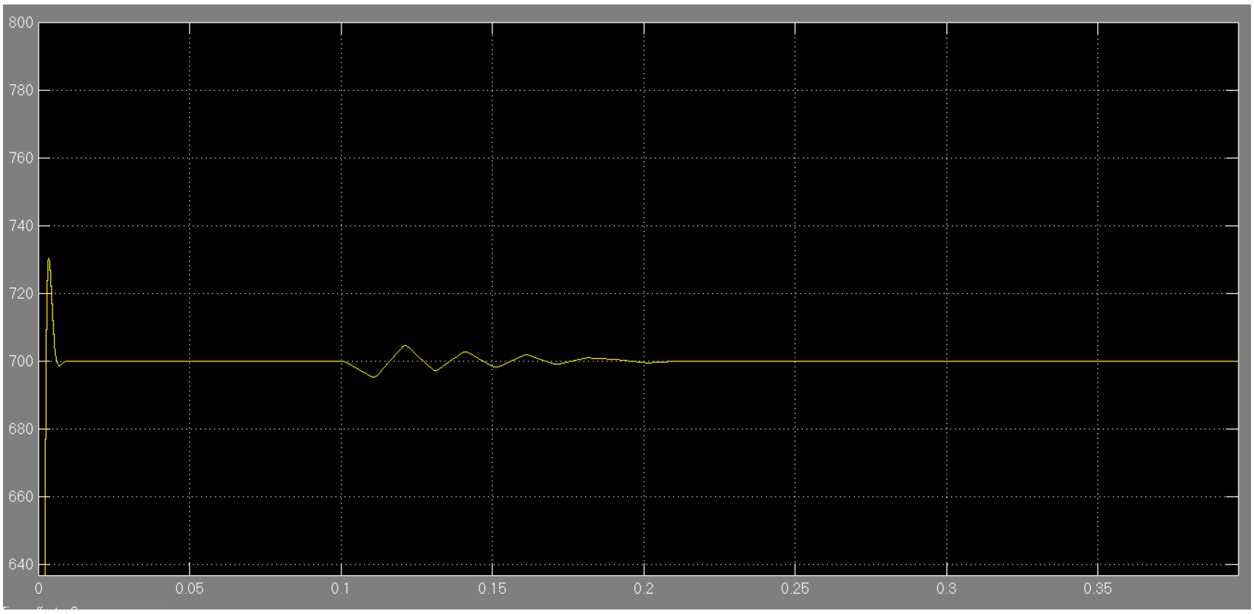
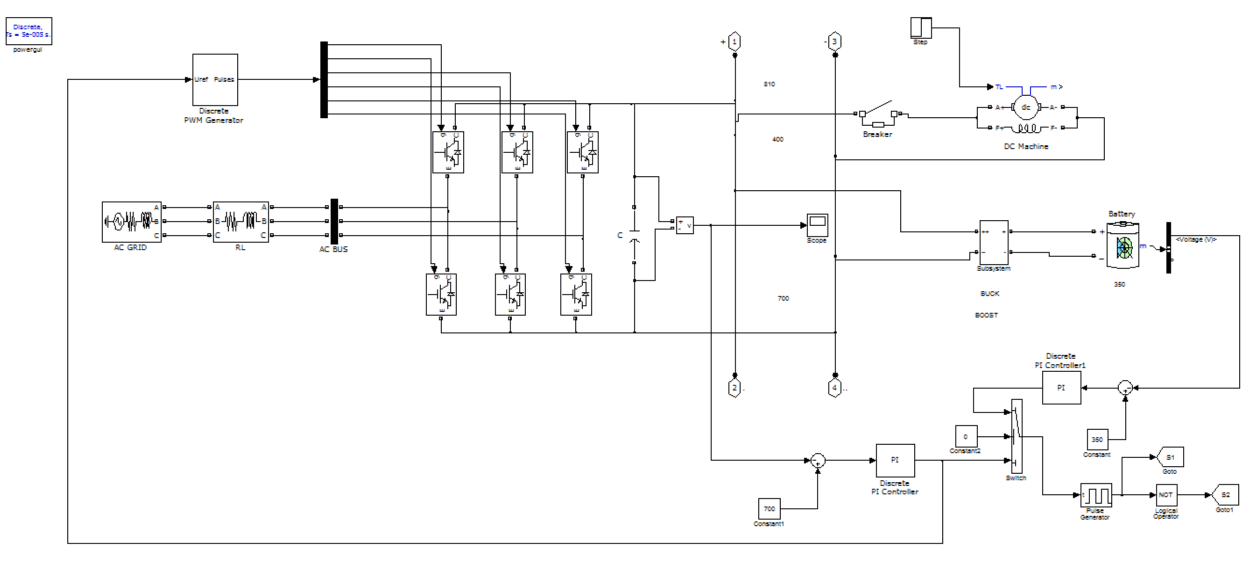


DC LINK VOLTAGE WITH POWER CHARGING METHOD



PROPOSED CIRCUIT CONFIGURATION WITH VOLTAGE CHARGING METHOD

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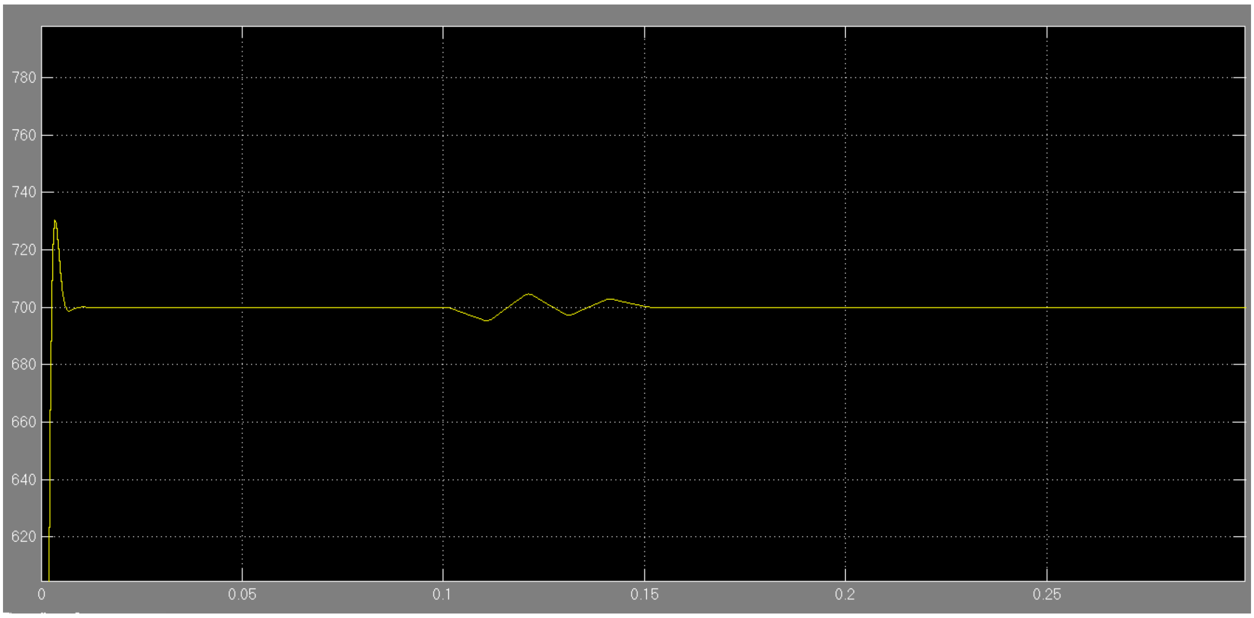

DC LINK VOLTAGE WITH VOLTAGE CHARGING METHOD

CONCLUSION

A method was proposed for enhancing the stability of a dc distribution system intended to integrate EVs with an ac power grid. The dc distribution system is interfaced with the host ac grid via a VSC and can also embed DC modules. Thus, bidirectional dc–dc power-electronic converters act as battery chargers and interface the EVs with the dc distribution system, while DC modules are interfaced with the dc distribution system via unidirectional dc–dc converters. It was demonstrated the proposed stability enhancement method mitigates the issue of instability by altering the power set points of the battery chargers, without a need for changing system parameters or hardware. The project presented mathematical models for the original and modified systems and demonstrated that the proposed technique expands the stable operating region of the dc distribution system. Simulation studies were conducted to demonstrate the effectiveness of the proposed method.

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