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DESIGN OF A THREE-PORT INTEGRATED TOPOLOGY TO INTERFACE ELECTRIC VEHICLES AND RENEWABLE ENERGY SOURCES

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ABSTRACT

This work proposes the design and analysis of an off-board Three-Port Integrated Topology (TPIT). TPIT is used to interface Electrical Vehicles (EVs) and Renewable Energy Sources (RES) from solar electrical phenomenon (PV) panels with the power grid. The TPIT consists of three power converters sharing one common DC link. It can be operated in four completely different modes towards the long run sensible grids. The EV battery area unit is charged with energy from the power grid through the Grid-to-Vehicle (G2V) operation mode. The EV batteries deliver a part of the stored energy back to the power grid through the Vehicle-to-Grid (V2G) operation mode. The energy created by the PV panels is delivered to the electrical grid through the Renewable-to-Grid (R2G) operation mode and the energy created by the PV panels is employed to charge the EV batteries through the Renewable-to-Vehicle (R2V) operation mode. In addition to individual action, the reorganization of those modes leads to hybrid operational modes. This work plan is to propose a power theory to regulate the TPIT and this current control strategy controls the current in AC and DC sides of the TPIT respectively. Also, the features of the developed TPIT prototype, including the hardware and the digital control system are designed. The result portrays the analysis of TPIT operation modes are presented.

Keywords: electric vehicle, integrated topology, renewable energy sources, smart grid.

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1. INTRODUCTION

1.1 Electric Vehicles

Electric Vehicles (EVs) are gaining momentum due to several factors, including price reduction as well as the climate and environmental awareness. EVs will have a very important role in Smart cities, along with shared mobility, public transport, etc. Therefore, more efforts to facilitate the charging process and to improve batteries are needed. The main drawback of the EVs is their autonomy. However, researchers are working on improved battery technologies to increase driving range and decrease charging time, weight, and cost. These factors will ultimately determine the future of EVs. The evolution of electrical vehicles throughout history, give diverse classifications according to the manner in which they have been designed and the characteristics of their engines or analyze their impact on the electrical infrastructure. The history of EVs from their creation, in the middle of the nineteenth century, until present. Additionally, they carry out a classification of the vehicles according to their power train settings. Finally, their work analyze the impact of charging electric vehicles on the electric grid. The effects that EVs can produce in the required productivity, efficiency, and capacity of the electric grid. Furthermore, he reviews the economic and environmental impact of electric vehicles. A review of charging methods for electric vehicles and analyze their impact in the power distribution systems. Much research is carried out an analysis of coordinated and non-coordinated charging methods, delayed loading, and intelligent planning of charges. Finally, the study the economic benefits of the vehicle-to-grid (V2G) technology according to the charging methods.

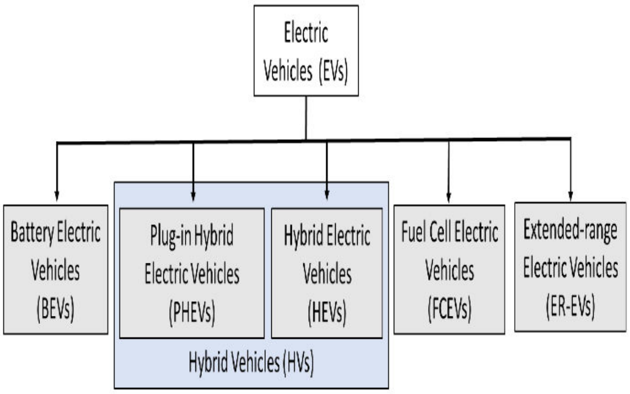

Figure-1. Electric vehicles classification.

1.2 Renewable Energy Sources

Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health. Furthermore, they tend to be cyclical in nature, due to the effects of oligopoly in production and distribution. These traditional fossil fuel-based energy sources are facing increasing pressure on a host of environmental fronts, with perhaps the most serious challenge confronting the future use of coal being the Kyoto Protocol greenhouse gas (GHG) reduction targets. It is now clear that any effort to maintain atmospheric levels of CO2 below even 550 ppm cannot be based fundamentally on an oil and coal-powered global economy, barring radical carbon sequestration efforts. Renewable energy sources currently supply somewhere between 15 percent and 20 percent of the world's total energy demand. The supply is dominated by traditional biomass, mostly fuel wood used for cooking and heating, especially in developing countries in Africa, Asia, and Latin America. A major contribution is also obtained from the use of large hydropower; with nearly 20 percent of the global electricity supply being provided by this source. New renewable energy sources (solar energy, wind energy, modern bio-energy, geothermal energy, and small hydropower) are currently contributing about two percent. A number of scenario studies have investigated the potential contribution of renewable to global energy supplies, indicating that in the second half of the 21st century, their contribution might range from the present figure of nearly 20 percent to more than 50 percent with the right policies in place.

1.3 Photovoltaic Cells

A solar cell (or Photovoltaic Cell) is a device that produces electric current either by chemical action or by converting light to electric current when exposed to sunlight. For the sake of this article, attention will be given to solar cells only. A solar cell is also known as photovoltaic cell which produces electric current when the surface is exposed to sunlight. In the course of this article, we will be making reference to sunlight as electromagnetic radiation (EM-radiation).In solar cells, the amount of electrical energy generated by the cells depends on the intensity of the EM radiation that reaches the surface of the cell. A solar cell converts the EM radiation to DC current. Thus, we can say that a solar cell is a semiconductor junction device that converts electromagnetic radiation reaching us from the sun to electrical energy. As stated above, the current generated is DC.

1.3.1 Risks with batteries

Batteries are prone to accidents like leakage and explosions which are caused mainly due to mishandling or misuse of the batteries. While an explosion may result from misuse like throwing in a flame, attempting recharge of a primary cell, short circuiting, overcharging, etc., leakage is mainly either due to manufacturing defects or the storage conditions like temperature, humidity and position. This may result in the leakage of potentially corrosive materials as in the case of a few batteries like Lead Acid and do damage to the equipment in which these have been installed. The use of environmentally dangerous materials like mercury in the batteries has raised widespread concern and has called for various constitutional acts of restrictions on battery materials.

1.4 Electrical Grid

Electrical grids are adapting to become more resilient and renewable. As the pressing need to decrease carbon emissions motivates incentives for and development of renewable energy, so also increases the need for electric grids to be able to withstand and recover from more frequent and severe natural disasters. In addition, adversarial cyber and physical human threats are becoming more sophisticated and devastating. Two major themes, renewable energy integration and resiliency of power systems, are driving great changes in the operation and planning of electrical grids. These two themes are intertwined for several reasons. First, both are currently being addressed by electric utilities. Second, the need to incorporate uncertainty analysis is necessary for both generator scheduling with renewable generation and for assessing the risk of natural disasters and cyber security threats in resiliency analysis. Last, distributed renewable generation has in part driven the increase in the digitalization of the grid that in turn poses cyber security risks and monitoring requirements. The digitization of the electrical grid has proven to be a great asset in developing the advanced monitoring and forecasting abilities necessary for high contributions of non-dispatchable and variable inverter-based renewable energy sources (VIBRES); however, the advent of massive amounts of critical infrastructure data and new communication frameworks also poses significant cyber security risks.

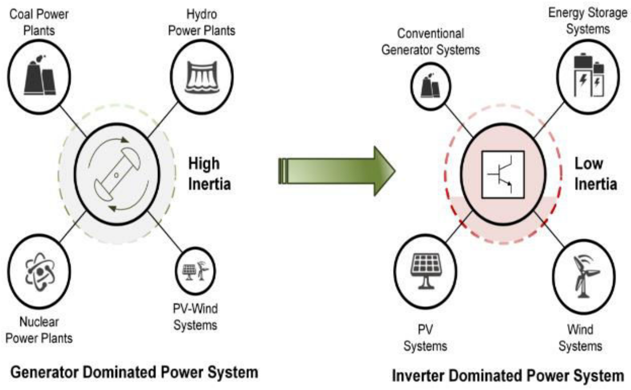

Figure-2. Evolution towards variable inverter-based renewable energy sources.

The automation increase has also spurred investigation into self-healing. Inherent system resilience is becoming an important factor in longer-term system topology evolution studies, as well as probabilistic planning and operations studies. At the shorter time scale of power system events, machine learning has been leveraged against the growing power system data sets to evaluate resilience more acutely. These topics include cyber-physical analysis of solar, wind, and DERs, microgrids, network evolution and observability, substation automation and self-healing, and probabilistic planning and operation methods. However, in comparison to the research works solely addressing resilience in power systems or the evolving electrical grid, there are far fewer research works at the intersection of these topics. There is a research gap and a clear need for research to incorporate this two topic together and holistically.

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2. LITERATURE REVIEW

Electric mobility represents a significant contribution to increase sustainability and efficiency in the transport sector [1] [2], including the use of electric vehicles (EVs), hybrid EVs, fuel cell vehicles [3], and electric bicycles [4]. Nevertheless, the massive introduction of EVs into the electrical grid should be controlled in order to prevent power quality problems [5][6], to optimize its interaction with other electrical appliances [7], as well as to take advantage of their use in the new paradigms of microgrids [8], smart grids and smart homes [9]. In this context, the optimized EV charging process considering the customer perspective, the power demand, and the revenue of the aggregator is presented. Besides the controlled charging process, the introduction of EVs into the electrical power grid to exchange energy in bidirectional mode through the grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operation modes is presented in [11].

In addition, with the progress in micro generation, new opportunities also emerge for the integration of EVs with renewable considering different electrical grid constraints [19]. In this context, the contribution of EVs to stabilize the electrical grid voltage considering the introduction of renewable is presented in [20]. Besides the EV operation considering renewable energy sources, the incorporation of energy storage systems is also relevant for energy management in smart grids.

3. PROBLEM DESCRIPTION

3.1 Existing System

The main disadvantage of traditional topology is associated with the direct EV battery charging process from renewable sources, where it is necessary to use four converters and the electrical grid as an intermediary (DC to AC stage followed by an ac to dc stage). In order to side step this drawback, this paper presents the experimental validation of a single-phase off-board three-port integrated topology (TPIT) for residential purpose, aiming to interface EVs and renewable with the electrical grid through an ac-dc converter and two DC-DC converters. Figure-1 presents the interface between an EV and PV panels with the electrical grid using the classical topology.

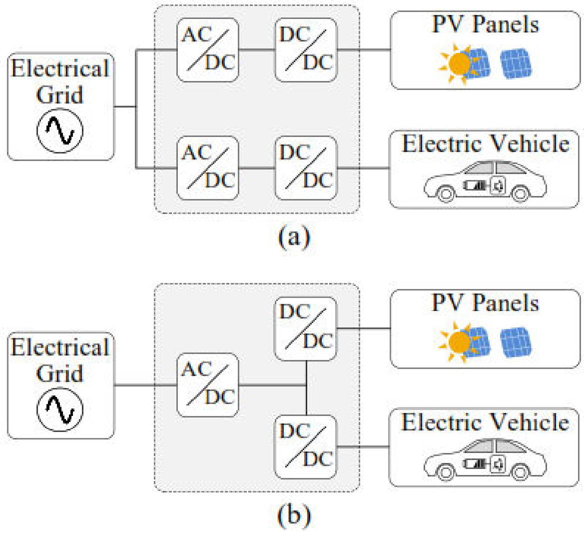

Figure-3. Interface between an EV and PV panels with the electrical grid: Classical topology (b) Proposed topology.

Figure-4 shows the interconnection between the TPIT, the EV, the PV panels, and the electrical grid.

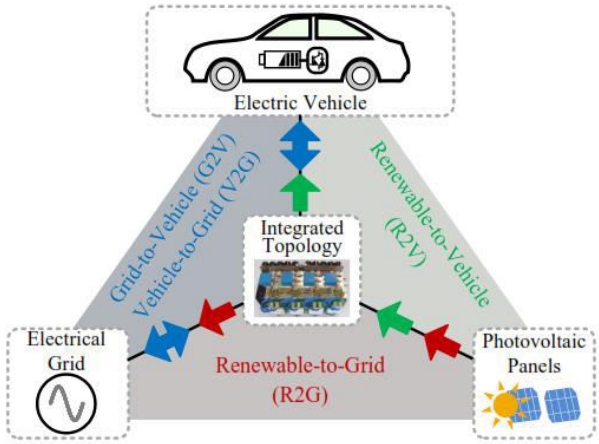

Figure-4. Three-port integrated topology (TPIT) used to interface electric vehicles (EVs) and renewable from photovoltaics (PV) with the electrical grid through the G2V, V2G, R2V and R2G operation modes.

3.2 Proposed System

The circuit schematic of the TPIT is presented Figure-5, where is presented the ac-dc bidirectional full-bridge converter used to interface the power grid, the dc-dc bidirectional half-bridge converter used to interface the EV batteries, and the dc-dc unidirectional half-bridge converter used to interface the PV panels. In addition to the previously highlighted advantages (cf. section I), this topology was selected due to the possibility of integrating the three converters in a single dc-link, maintaining the characteristics of each converter. The EV is not galvanic isolated from the PV or from the power grid, since the galvanic isolation only must be guaranteed between the traction batteries and the vehicle chassis according to the IEC 61851-1 standard. The operation of the TPIT is

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defined according to the EV operation mode (G2V or V2G) and the available energy from the PV panels (R2G or R2V). Therefore, a power theory should be defined in order to establish the current references for the TPIT operation according to the different operation modes.

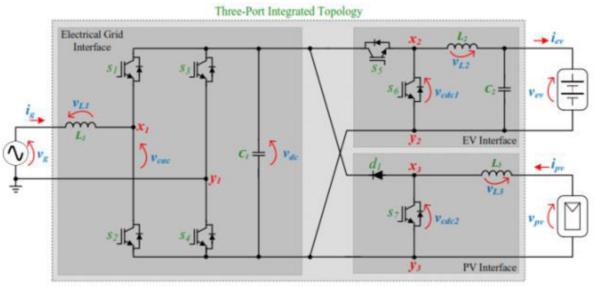

Figure-5. Circuit of the proposed three-port integrated topology (TPIT) used to interface EVs and renewable with the electrical grid.

3.3 Three-Port Integrated Topology (TPIT)

Taking into account that the TPIT operates with sinusoidal grid current, the grid current reference (*ig**) is determined using a power theory, i.e., it is obtained a signal directly proportional to the electrical grid voltage (*vg*). In the scope of this paper, the power theory is based on the Fryze-Buchholz-Depenbrock (FBD) method, where a converter can be seen as a conductance (*GG*). From the electrical grid point of view, the TPIT can operate as a linear load (consuming sinusoidal current in phase with the voltage, i.e., as an active rectifier) or as a current source (injecting sinusoidal current into the electrical grid in phase opposition with the voltage, i.e., as a grid-tie inverter). The EV current (*iev*) is controlled according to its reference established by the battery management system (BMS)(cf. section II.B). Since the instantaneous values of all the ac and dc variables are acquired by the digital control system (with a sampling frequency of 40 kHz), the operating power in each port is automatically calculated by the control system with the same sampling rate. Analyzing is possible to verify that the grid current (*ig*) is also directly influenced by the grid voltage (*vg*), meaning that the harmonic distortion presented in the grid voltage will be reflected in the grid current. Directly using the measured grid voltage represents a disadvantage, since the TPIT would contribute to aggravate the problem of harmonic currents in the electrical grid. To avoid this drawback, instead of using the measured voltage it is used a signal proportional to its fundamental component, i.e., a sinewave signal with the fundamental frequency of the electrical grid (50 Hz - in Europe). This signal is obtained from a phase-locked loop (PLL) algorithm.

3.4 System Requirements

This proposed system comprises of Arduino, current sensor, solar, battery, LCD, buzzer. Normally load takes power supply from grid. Bluetooth is nothing but wireless module. The controller reads the data from the controller. Whenever peak time persists automatically share the renewable battery power. DC to DC converter is used to convert renewable energy to AC energy. The controller is used to send the calculated amount of grid and renewable energy use to the EB section. The current sensor is used to measure the line voltage. Here current sensor is used to protect the devices from faults like 1. Over voltages 2.Under voltage. If any one of the above problem persists the device automatically share or switch off the device. Controller status is displayed in LCD. The whole process is controlled by a microcontroller. The minimum hardware and software requirements are specified below.

3.5 Hardware Requirements

- Power Supply
- Arduino microcontroller
- Solar Panel
- Battery
- Current sensor
- LCD Display
- Lamp load
- DC to DC converter

4. DESIGN AND IMPLEMENTATION

4.1 Operation of the Three-Port Integrated Topology (TPIT)

Figure-6 shows a typical operation of the TPIT considering the G2V, V2G, R2V and R2G modes, where, *vg* denotes the electrical grid voltage, *ig*means the current in the electrical grid, and *pg*, *pev*, *ppv*are, respectively, the grid power, the EV power and the PV power. These results were obtained with computer simulations using the software PSIM v9.0.

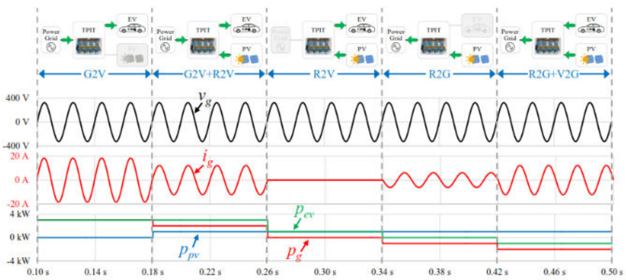

Figure-6. Principle of operation TPIT.

During the firsttime interval (from 0.1 s to 0.18 s) the TPIT is controlled to operate in G2V operation mode, i.e., the EV batteries are charged with energy provided only by the electrical grid. Therefore, the value of the grid power (*pg*) is equal to the value of the EV power (*pev*). During the second time interval (from 0.18 s to 0.26 s), the TPIT is controlled to charge the EV batteries (G2V operation mode) and to extract the maximum power from the PV panels (R2V operation mode), i.e., the EV batteries are charged with energy provided by the electrical grid and by the PV panels. Therefore, the value of the grid power (*pg*) is the difference between the EV power (*pev*) and the PV power (*ppv*). During the third time interval (from 0.26s to 0.34 s), the TPIT is controlled to charge the EV batteries (G2V operation mode) and to extract the maximum power from the PV panels (R2V operation mode), where, the EV batteries are charged with energy provided only by the PV panels. Therefore, the value of the PV power (*ppv*) is equal to the EV power (*pev*). During the fourth time interval (from 0.34s to 0.42 s), the TPIT is controlled to extract the maximum power from the PV panels (R2G operation mode) and to inject it into the electrical grid. Therefore, the value of the PV power (*ppv*) is equal to the grid power (*pg*). The negative value of *pg*means that the electrical grid receives energy.

4.2 Implementation of the TPIT

The potential transformer will step down the power supply voltage (0-230V) to (0-6V) level. Then the secondary of the potential transformer will be connected to the precision rectifier, which is constructed with the help of op-amp. The advantages of using a precision rectifier are it will give peak voltage output as DC; rest of the circuits will give only RMS output.

4.3 Input and Output

Serial: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip. External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attach Interrupt () function for details.PWM: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the analogWrite() function.SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication using the SPI library. LED: 13. There is a built-in LED driven by digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off. TWI: A4 or SDA pin and A5 or SCL pin. Support TWI communication using the Wire library.The Uno has 6 analog inputs, labelled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). AREF. Reference voltage for the analog inputs. Used with analogReference(). Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

5. CONCLUSIONS

This work presents a Three-Port Integrated Topology (TPIT) which is used to interface an Electric Vehicle (EV) and Renewable Energy Sources (RES) from photovoltaic (PV) panels with the Electrical Grid. With the proposed topology, it is possible to reduce the number of conversion stages in comparison with a classical topology, also allowing the definition of new operation modes and control algorithms, without neglecting the power quality in the electrical grid side. The proposed TPIT is designed in four main operation modes, where it is possible to deliver energy from the PV panels to the EV or to the electrical grid and to exchange energy in bidirectional mode between the EV and the electrical grid. This project work in phase II will focus on various algorithms to control the TPIT based on the Fryze-Buchholz-Depenbrock (FBD) power theory, the predictive current control strategies, and the hardware to be developed, will include the power converters and the digital control system. The simulation result validates the benefits of the proposed topology, including the operation with sinusoidal grid current and low Total Harmonic Distortion (THD) in all the operating modes.

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