A Research on The Economic and Technological Feasibility of The Proposed Grid-Connected Hybrid Renewable Energy System in Process Industries

Pardeep Rana (Engineering), Research Scholar, SunRise University, Alwar(Rajasthan)
Dr. Ram Mohan Singh Bhadoria (Engineering), Associate Professor, SunRise University, Alwar(Rajasthan)

ABSTRACT

The power generated by solar panels and wind turbines to the present electrical grid, we will be able to build a hybrid renewable energy system that is both reliable and self-sufficient. Current harmonics induced by non-linear loads at load centres may be suppressed at a cheap cost by including a harmonic mitigation feature into the grid-interfacing inverter. The inverter controller is made up of two loops: one that controls the DC connection voltage and the other that reduces the harmonic content of the current. Current DC-link voltage controllers include chattering, steady-state inaccuracy, and a lack of stability margin. When grid voltage levels are less than optimal, the frequently employed inner loop controller, which is based on PQ theory, operates badly. Traditional techniques to fundamental component extraction in PQ theory based on low pass filters have various drawbacks, one of which is the possibility of excessive delays and low-frequency oscillations.

Keywords: Hybrid Renewable Energy, Technological, Feasibility, Grid-Connected.

1. INTRODUCTION

Energy is quickly becoming recognised as a basic necessity of modern life, right up there with food, clothing, and shelter. Potentially positive and negative outcomes for humanity could result from this Energy. From a pragmatic standpoint, energy improves our quality of life by providing us with an abundant supply of electricity that is not only cheap, but also safe and environmentally friendly. On the other hand, energy production, transportation, and storage could have negative effects on human health, environmental quality, and the economy. However, the availability of an adequate and consistent supply of high-quality energy is crucial to the achievement of success in a variety of economic endeavours. There will be a 30% increase in energy consumption worldwide by 2040, as reported by the World Energy Outlook 2017. 40% of this expansion will come from renewable energy. India was responsible for a third of the world's increased energy consumption. In addition, there is a long-term environmental threat posed by the burning of fossil fuels to generate electricity. There are a number of approaches that can be taken to fix this issue, but one of the most effective ones is to educate people about renewable energy options that are easier on the environment. Solar, wind, hydro, biogas, biomass, tidal, wave, and ocean thermal power are just a few examples of renewable energy. Particularly attractive to residents of rural areas are energy mix arrangement choices that give preference to the generation of power from locally-owned resources.[1]

1.1. Renewable Energy Sources

Renewable energy has an almost infinite supply because it is constantly renewed by natural processes, making it an excellent choice for power generation. In theory, the amount of energy produced by the sun each day is more than enough to power the entire world's population for an entire year. Nonetheless, the availability of solar energy and other renewable energy sources may vary substantially across time and geography.[2]

In certain places of the world, wind power and/or solar electricity might be quite useful. High solar energy potential exists in the southwestern United States, northern Africa, the Middle East, and certain areas in Australia and South America. The southernmost point of South America, Northern Europe, and the Great Lakes area of the United States are some of the places where best places in the world to harness the power of the wind. Certain nations, such as Iceland and the Philippines, have easy access to geothermal energy. Renewable energy sources can be found in any region of the world, though their accessibility and prices may vary from one region to the next. [3]

i. Biomass

Biomass refers to any fuel that was recently processed from plant matter. This includes everything from wood and crops to agricultural waste and animal feces. Biomass can be anything from crops to wood to discarded wood and hay. Both fossil fuels and biomass were once readily available for industrial use. Extraction of energy from biomass has been crucial to human survival since the invention of fire. At least 10% of the world's primary energy supply comes from biomass. This is because a significant portion of the global population still relies heavily on traditional cooking fuels like wood, charcoal, straw, and animal dung.

ii. Hydropower

The optimal sites for hydroelectric power production have both high head and high flow. The electricity that is produced in these locations is significant and very affordable. However, similar to the energy potential of biomass, such areas have a finite amount to provide.[4]

The development of hydropower in each country is quite different from that of the other nations. Others such as Switzerland and Mexico have made significant progress toward realizing their full technical potential, but countries such as Norway and Sweden have only made around half of the necessary progress. Comparatively, the United States has only developed 16% of its technical potential, whereas China has only realized 24% of its technological potential. Those regions that have a lengthy history of harnessing the power of hydroelectricity are the ones in which the best possible locations have already been used, which drives up the price of new construction. On the other hand, in a world where renewable energy sources predominate, the price of electricity may rise, which might make more areas desirable for the development of hydropower. [5]

iii. Wind power

This indicates that, over a year, the plants may create more than 90% of the energy they would acquire if they ran continuously at maximum production for the whole year. This is because the plants are functioning at full capacity for the entire year. In contrast, the capacity factor for producing electricity from wind might be as low as 30 percent at a good location and much lower at a poor one. The low capacity factor of wind power is frequently mentioned as a cause for its unfavorable reception; however, in reality, this is only a concern when it comes to cost.

Wind power, much like every other kind of energy, is associated with its own unique set of unwanted effects. The most prominent ones are the visual effect of the wind turbines, which may reach heights of over 400 feet, the noise caused by the wind in the turbine blades, which can be a nuisance for those living nearby, and the death of birds as a result of collisions with the blades of the turbines. All of these factors contribute to the visual effect of wind turbines.[6]

iv. Direct Solar Energy

Sunlight can be converted into one of three distinct types of solar power:

- Solar energy operates at a mild temperature
- energy that is not extracted from the ground, such as solar panels and photovoltaic cells.
- sun thermal energy at high temperatures.

In many regions of the world, the price of heating water using solar energy has already decreased to a point where it is on par with the price of using fossil fuels. However, the economics of solar space heating is made more complicated by the fact that the peak demand for heating energy occurs in the winter, when there is the least amount of sunlight available, and summer, when there is the most amount of sunlight available and the least amount of demand for heating energy.[7]

1.2 Energy and sustainable development

In both emerging and established nations, energy systems may be a major source of environmental damage. A sustainable global energy system, therefore, would allow us to maximize productivity while also cutting down on pollution. Sustainable and steady growth is essential for not just the global economy but also the advancement of technology. Inevitably, global environmental issues will worsen as energy use, particularly from fossil fuels, continues to rise. To achieve sustainable development, both developed and developing nations are making plans to implement the most suitable energy systems and to better the lives of their citizens and the state of the planet. Some variables, such as demographic, social, economic, and technological trends, may challenge the long-term sustainability of global energy systems. Energy diversity and efficiency, supply reliability, public trust, market-sensitive interventions, market-based climate change responses, cost-reflective prices, technological innovation and development, regional integration of energy systems, and cost-reflective pricing are all crucial to achieving sustainable energy systems. [8]

2. LITERATURE REVIEW

Hajizadeh, A. and Golkar, M. A. (2017) a hybrid power plant using photovoltaic cells and fuel cells was designed and modeled by the author. An electrolyzer for producing hydrogen was incorporated into the system that was proposed. The fuzzy regression model was implemented in the proposed system so that maximum power point tracking, which is used to extract the maximum amount of energy possible from solar PV arrays, could be accomplished. A controller was incorporated into the design to ensure that a consistent flow of energy was maintained from the photovoltaic array, fuel cell, or both to the load. An isolation circuit, which keeps the electrolyte and the electrolysis cell from coming into contact with one another and thus prevents the electrolyzer's electrodes from corroding when the sun goes down, is the innovative component of the system that has been proposed.[9]

Jean-Jacques Slotine, W. L. (2015)have developed a system that combines photovoltaic panels, electrolyzers, and fuel cells to provide off-grid facilities with electricity that is dependable, consistent, and kind to the environment. Additionally, the module was validated for its potential application in off-grid telecommunications as well as healthcare. The procedures must be followed to achieve the greatest possible increase in the amount of power that is transferred from a PV array to a PEM electrolyzer that is connected in series. The photovoltaic panels and the PEM cell were wired in the most efficient combination of series and parallel connections possible. In actual practice, the capacity of 75 Watts provided by four PV modules was directly coupled with the capacity of 50 Watts provided by five PE Melectrolyzer stacks. [10]

Ghosh, A., and Joshi, A. (2017)wind, fuel cells, and ultra-capacitor devices are just a few examples of renewable energy sources that have been cited as needing to be integrated efficiently to assure continuous power supply. They recommended merging the two UC technologies because of the inherent variability in the quantity of power produced by wind turbines. Because of this, you may be certain that the system's efficiency is impervious to environmental influences. The dynamic model that comprised the wind/FC/UC hybrid power generating system relied heavily on the functionality of the power flow controllers. In this study, a novel architecture is introduced to manage voltage variations due to rapid changes in wind speed. The technology has effectively reduced the impact of voltage fluctuations on the connected equipment.[11]

Zeineldin, H. H., and Singh, B. (2018)have developed and field-tested a hybrid power system consisting of wind turbine photovoltaic fuel cells (FC) and ultracapacitor (UC) devices, allowing for grid-independent applications. The maximal command is attained by the use of a control system that ensures optimal overall system performance. This research's control system was developed to maximize efficiency across the board and extract all of the power available from the WT and PV installations. Surplus energy can be stored in ultracapacitors, and hydrogen can be produced in electrolyzer cells, thanks to the system's architecture. The FC system was powered by hydrogen from the storage tank when energy production from the WT and PV systems fell short of meeting the load demand. Any imbalance in load demand brought on by the FC system is, according to the control system, immediately remedied by an ultra-capacitor bank. [12]

3. METHODOLOGY

The PMSG generator from a 15 kWp horizontal axis wind turbine will be investigated here. Removing the gearbox is the main benefit of a PMSG-based wind power system. If the system can be made lighter and cheaper, its efficiency and effectiveness will improve. The 15 kWp series-parallel arrangement of solar PV modules will be considered in the study. A hybrid wind-solar system will connect to the grid through a shared DC link and DC-AC power converter. A wind or solar power system's components will include DC-DC boost converters, DC-link capacitors, DC-AC power converters, AC filters, and non-linear loads.

- **Research Design**

DC output from wind and solar power plants will be different. DC-DC boost converters and Maximum Power Point Tracking (MPPT) in a solar power system will smooth out the DC voltage fluctuations so that all of the DC components can share a common DC link. Booster Converter Number 26 In order to find the optimal voltage for operation at the PV terminal, the duty ratio must be optimized. The PMSG's optimum rotor speed across the PMSG's range of wind speeds is determined by adjusting the PMSG's duty ratio to the corresponding booster converter in the wind power system.

- **Sample**

The Xilinx Basys3 FPGA is equipped with two 12-bit bipolar ADCs that can sample at one mega sample per second (MSPS). The analog-to-digital converter (ADC) has an input voltage range of 0.5 volts and can take up to four additional analog signals as inputs. The maximum amount of DC offset that is allowed is 0.5 V. With a maximum sampling rate of 250 kilo samples per second, the analog-to-digital converter (ADC) can simultaneously process up to four distinct signals.

4. RESULT

4.1 Steady state condition

The performance of the controller is analyzed concerning two different scenarios.,

- renewable energy sources produce more electricity than is needed to meet demand $(P_{RES} > P_L)$.
- The amount of energy provided by renewable sources is inadequate to meet current demands $(P_{RES} < P_L)$.

Waveforms at a constant frequency for $P_{RES} > P_L$ Figure 4.2 shows (a). Here, though, 12 m/s Considerations include wind speed and solar radiation of 1 kW/m2.

Figures for active power, DC-link voltage, grid voltage, grid current, load current, compensation current, and grid current for $P_{RES} > P_L$ appear in Figure 4.2 It has been noted that the power generated from renewable sources is sufficient to meet load demand and that any surplus is fed back into the grid. Every phase's grid current and voltage is asynchronous by/in real-time as the power is being added to the grid. A look at the steady-state waveforms for $P_{RES} < P_L$ Figure 4.2 shows (b). Three meters per second of wind and two hundred fifty W/m^2 aspects of solar radiation are taken into account.

Since it was determined that the total amount of power generated by renewable sources was not sufficient to meet the demand of the load, power was transferred from the grid to the load to satisfy the demand. The current and voltage of the grid for each phase are synchronized with one another. In either case, the BSC-DSTF controller that was proposed achieves its goal of reducing grid current harmonics to a level that is lower than the threshold that was recommended by the IEEE.

In this study, comparisons are made between the steady-state performance of the BSC-DSTF controller and that of the PILPF controller, the PI-DTSF controller, and the Fuzzy-DSTF controller.

- The voltage on the grid,
- Grid voltage imbalance,
- Grid voltage distortion
- Load imbalance difficulties.

The parts that follow will go through the findings from the comparison research at a constant state.

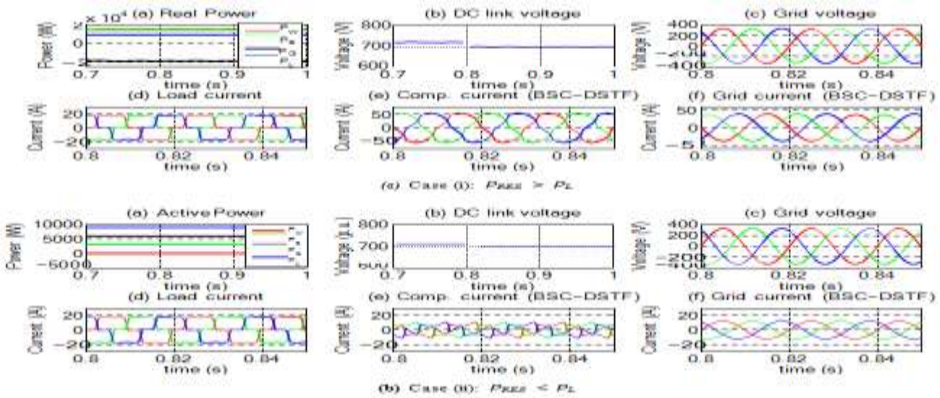

Figure 4.1: Waves in a steady state

i. Case 1: Optimal voltage for the grid

In this scenario, we assume a perfectly clean and balanced grid voltage. Non-uniform and evenly distributed stress is the case. Waveforms of grid voltage and current for $P_{RES} > P_L$ Figure 4.3 shows the PI-LPF, PI-DTSF, Fuzzy-DSTF, and BSC-DSTF controllers all applied to the same situation. The results of the harmonic analysis are shown in Figure 4.4. There appears to be no difference in the ability to reduce harmonic current between the PI-DTSF, Fuzzy-DSTF, and BSC-DSTF controllers. They excel in areas where the PI-LPF controller fails, including: some ways $P_{RES} > P_L$ scenarios, assuming perfect grid voltage.

The voltage and current waveforms at the grid level are displayed in Figure 4.5 for $P_{RES} < P_L$ condition. Figure 4.6 displays the outcomes of the harmonic analysis performed on this scenario. Here, the PI-DTSF, Fuzzy-DSTF, and BSC-DSTF controllers all outperform the PI-LPF in terms of their ability to reduce harmonic current. Consistent steady-state performance is achieved across all three controller types (PI-DTSF, Fuzzy-DSTF, and BSC-DSTF) here as well.

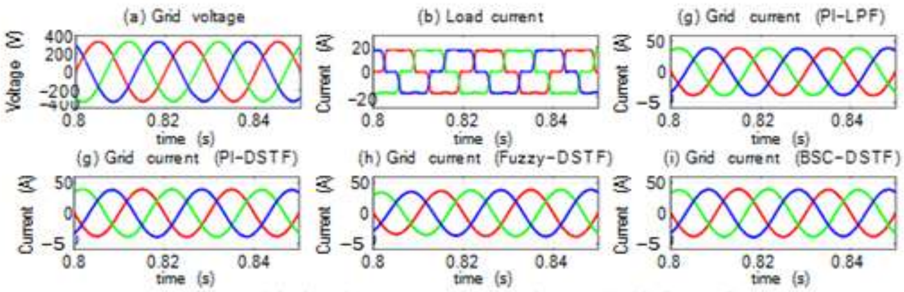

Figure 4.2: Steady-state wave from under case 1 with $P_{RES} > P_L$

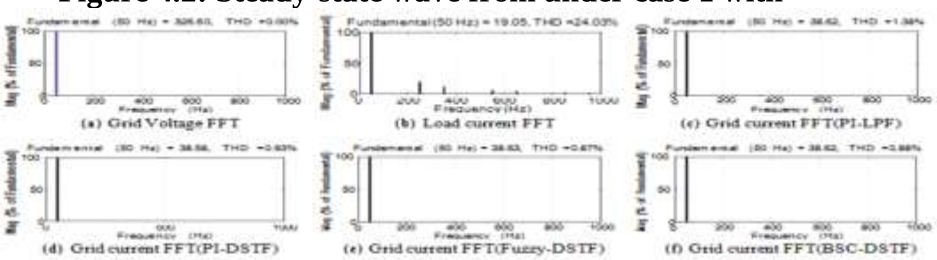

Figure 4.3: Findings from Phase A's Steady-State Harmonic Analysis in the First Case $P_{RES} > P_L$

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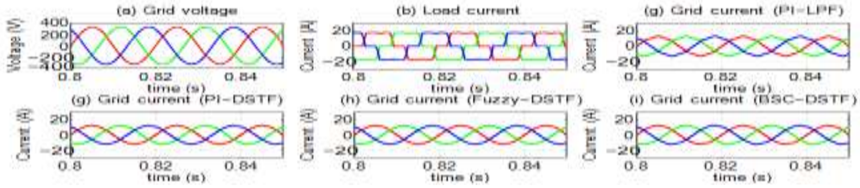

Figure 4.4: Steady-state waveforms under case 1 with $P_{RES} > P_L$

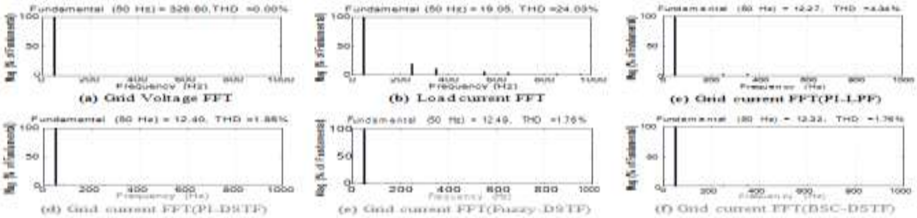

Figure 4.5: Steady-state harmonic analysis results of phase A under case 1 with $P_{RES} > P_L$

ii. Case 2: Unbalanced grid voltage condition

By boosting the voltage on phase A by 10% while maintaining the voltages on the remaining phases at their normal levels, we may mimic an imbalance in the grid's voltage. Balanced non-linearity characterizes the load. Waveforms of grid voltage and current, as well as conclusions from a harmonic analysis using all four potentiometers for $P_{RES} > P_L$ Figure 4.7 and 4.8, depict the current state of the situation graphically. If you utilize a PI-LPF controller, you'll see that the THD of the grid current rises over the recommended IEEE threshold. With PI-DTSF, Fuzzy-DSTF, and BSC-DSTF controllers, grid current THDs are all comparable and well within the allowed range.

Harmonic analysis findings and waveforms for grid voltage and current are shown in Figures 4.9 and 4.10 $P_{RES} < P_L$ state of affairs, in each case. Here, we additionally take into account the possibility of grid voltage imbalance. In this scenario, the findings reveal that the harmonic current mitigation provided by the PI-DTSF, Fuzzy DSTF, and BSC-DSTF controllers is superior to that provided by the PI-LPF controller. The three-phase THD of the grid current is well within IEEE limits.

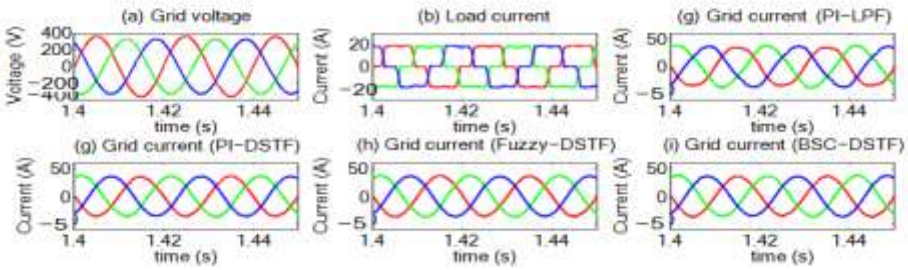

Figure 4.6: Steady-state waveforms under case 2 with $P_{RES} > P_L$

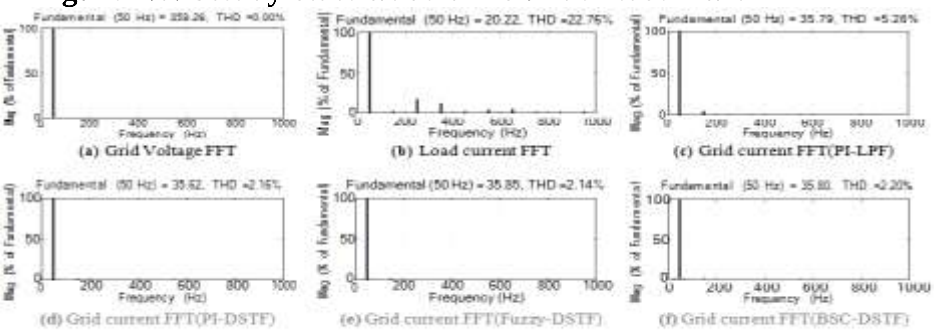

Figure 4.7: Steady-state harmonic analysis results of phase A under case 2 with $P_{RES} > P_L$

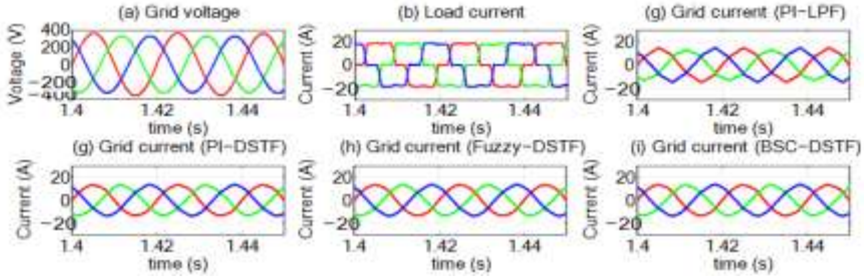

Figure 4.8: Steady-state waveforms under case 2 with $P_{RES} > P_L$

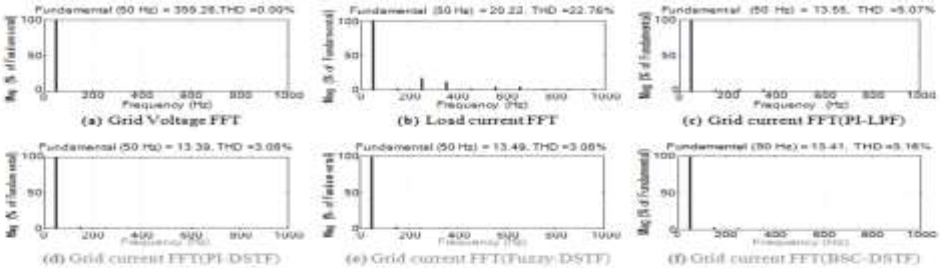

Figure 4.9: Steady-state harmonic analysis results of phase A under case 2 with $P_{RES} > P_L$

4.2 Dynamic conditions

Different dynamic behaviours of the system are examined under different conditions, such as at startup, rapid changes in wind speed or solar irradiance, abrupt shifts in load, and abrupt shifts in the DC-link reference voltage.

i. Starting

Dampening the excessive beginning current requires the use of an AC inductor filter that has a series of five resistors connected to it. After a certain number of cycles, the switch that is positioned across the resistor will become closed, removing the resistor from the circuit. Waveforms of the real power supply and DC link voltage are seen in Figure 4.19. When compared to PI-DSTF and Fuzzy-DSTF, it was discovered that the BSC-DSTF controller had a shorter reaction time for the DC-link voltage. The grid currents for each controller are shown in Figure 4.20 when the system is starting up. The beginning of the transients is brought on by the process of capacitor charging in the DC connection, as well as the dynamic behavior of the MPPT controller.

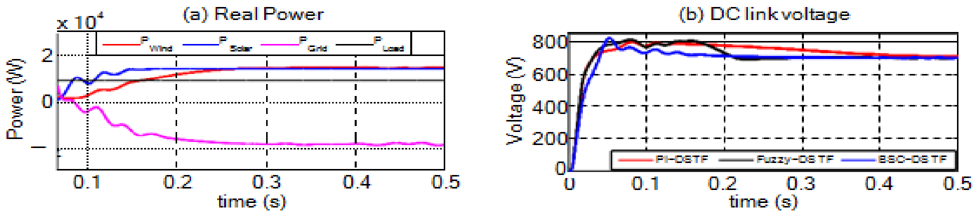

Figure 4.10: Start-up power and DC-link voltage plots

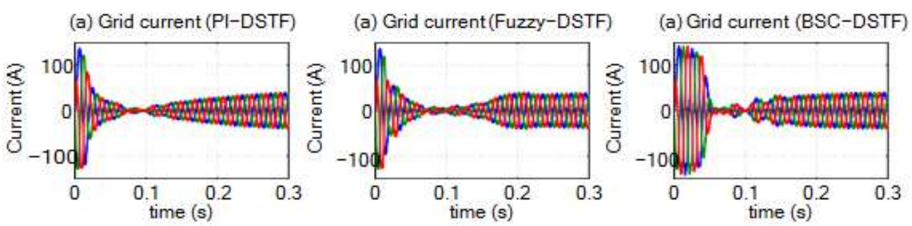

Figure 4.11: Starting current waveforms in the grid

ii. Step change in load

At the one-second mark, the simulation depicts a load reduction of fifty percent. Figure 4.21 depicts the waveforms of both the actual power and the voltage across the DC link during the load increment. It has been demonstrated that the BSC-DSTF controller offers a faster reaction for the DC-link voltage compared to the PI-DSTF controller and the Fuzzy-DSTF controller. This was determined by comparing the BSC-DSTF controller to the other two controllers. The currents in the grid are depicted in Figure 4.22 as they change as the load is reduced using a variety of controllers.

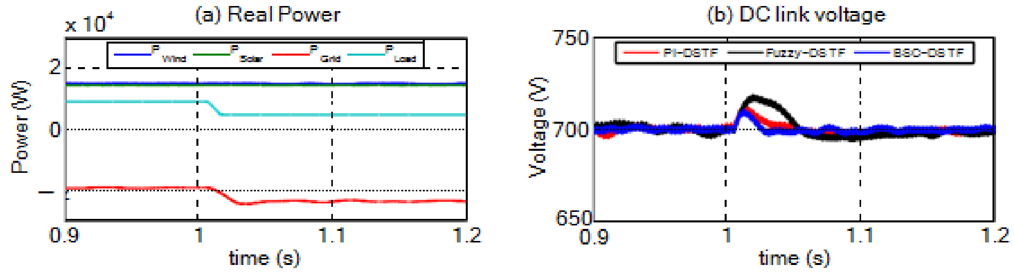

Figure 4.12: Graphs of power and DC-link voltage at 50% load reduction

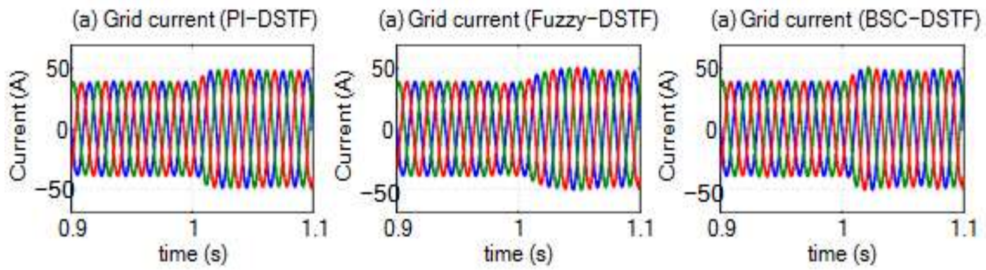

Figure 4.13: Waveforms of current in the grid with a step reduction of 50% load

To restore the load to its normal level, a 50% step increase is applied every 1.5 s. The waveforms of the grid current and the DC-link voltage are shown in Figures 4.23 and 4.24, respectively. The BSC-DSTF-pq controller also provides a quicker reaction time in this scenario.

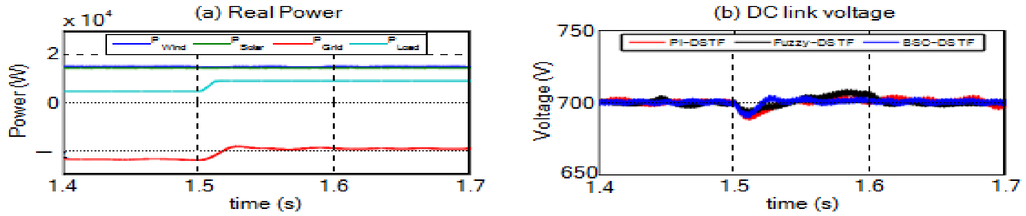

Figure 4.14: Schematics of power and DC-link voltage with each 50% load increase

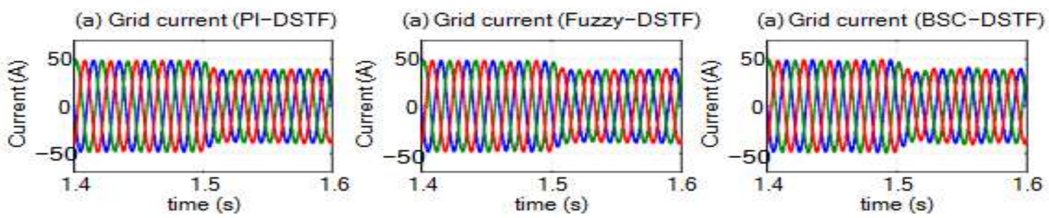

Figure 4.15: Power system current waves at a step load increase of 50%

5. CONCLUSION

In order to model the dynamic behaviour of the wind-solar hybrid system, the MATLAB/Simulink platform is used. For the DClink voltage controller, we show that the Back Stepping technique can be used to achieve reliable results. To more accurately compensate for system losses, the proposed Back Stepping Controller incorporates a separate switching loss estimator. The practical application of DSTF-pq theory in the construction of harmonic compensators is also discussed. With BSC in place, we can analyse the system with the Barbalat lemma to show that it is stable over a wide range of parameters. Using PI-DSTF, Fuzzy-DSTF, and BSC-DSTF controllers, the THD of the grid current is less than 5% in all steady-state simulated scenarios, which is well within the limits given by IEEE standard 519. We find that the suggested BSC-DSTF is superior to the PI-DSTF and Fuzzy-DSTF controllers in terms of speed, robustness, and dynamic performance over a range of dynamic scenarios.

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