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Reliable Control Strategy related to Hybrid Eenergy System for On-Grid Electrification of Villages in Weak-Grid Environment

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Method for on-grid electrification of villages. An improved control strategy is incorporated which enable the system to switch on in to grid and whenever required it can be set back to a micro grid. The studies are simulated in time-domain discrete mode using MATLAB™/Simulink™. Wind-fuel cell based hybrid energy system is tested with all possible control parameters and it is observed that the proposed control strategy is working satisfactorily.

Keywords: *Control strategy, Weak grid, Distributed energy sources and Village electrification.*

1.0 INTRODUCTION

The connection of micro generation to low voltage (LV) networks is deserved considerable attention from specialist's worldwide, encouraging investigations and pilot experiences. The electrical power system is accordingly getting change to address the requirements of market as well as consumers. The development in the power system is to provide continuous, reliable and qualitative power and improve network stability if distributed energy resource (DER) units are added with proper control and power management strategies. Nowadays it is necessary to make use of renewable energies and construct sustainable power systems [1]. Distributed generation systems (DGs) attract worldwide attention in recent years, including photovoltaic generation and wind power generation systems.

There are some countries in which more than 60% of the rural areas are outside the grid connection. Diesel is the main fuel for irrigation. But soaring prices of diesel and falling prices of PV, it is possible to use solar PV or wind or any other green source based irrigation on a commercial basis. Micro grid is only one of best solution for development of their electrical power improvement program.

Load shedding is a common phenomenon in weak grid markets because of lower utility power production and higher cost for distribution capacity (e.g., South East Asia or Africa). Power outages are happened one or several times in a day. The power quality is also poor in such environment. The villages which are located in off-grid areas and electrical line connection is not available or is not possible due to difficult geographical implication can be electrified by installing a central wind fuel cell hybrid power plant. The villages which are located in areas where electrical line connection is available either from national or from state grid connection is called on-grid environment. In this case energy can be supplied to grid also.

If grid is not connected to the supply source, the mode of operation is called islanded mode. In some cases, grid is connected to supply source and either power is being exported or imported to system from grid is called anti islanded mode of operation.

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In an average windy area having more than 4.5 m/s annual average wind speed, a 10 kW wind fuel cell hybrid power plant can provide the electrical power requirements for at least 20 small houses with each house consuming around 1.5 kWh or more energy per day for operating their CFL lights, small television or computer and fan. For villages having 100 such houses, a 50 kW wind fuel cell hybrid power plant would be sufficient. For villages having 200 such houses, a 100 kW wind fuel cell hybrid power plant would be enough to cater the load for 24 × 7 hours. The power plant size will be reduced in proportion to the local average wind speed.

Centrally located power plants can perform better than individual houses having small wind turbines home lighting systems as the central power plants have large capacity control/equipment which are more robust than smaller capacity fuel cell/wind power plants. Moreover central power plants can be monitored and maintained daily more effectively.

2.0 MICRO-GRID STRUCTURE

Micro grid power systems are small-scale power-generation solutions consisting of local power-generating facilities and individual homes and buildings equipped with wind and solar power systems. A key feature of the micro grid is that it will be seen by the distribution system as a singleload. Both the real and reactive power load can be controlled. Amicro grid may take the form of shopping center, industrial park, college campus or small villages. To the utility, a micro grid is an electrical load that can be controlled in magnitude. [4]

2.1 Wind turbine

There are many DERs available but as the place for which the study carried out is near to coastal area and proper wind potential is available. In this case, one of the sources considered as wind turbine. The selected wind turbine is having pitch angle control and synchronous generator to have better performance [2]. 100 kVA sizing is considered to take-care 50 kW balanced load for future expansion.

2.2 Fuel cell

Another source selected for this system is fuel cell as it is able to cater load any time if required gas is available. Fuel cell output voltage selected 1000 V DC to match with the DC bus of wind turbine. The coupling point selected is DC bus. Source capacity is selected as 100 kW to cater the 50 kW current loads and 50 kW load for future expansion.

3.0 INTEGRATED MICRO-GRID AND CONTROL PHILOSOPHY

Wind turbine is able to cater load while wind speed is in range of 6–18 m/s. In between this wind speed only wind turbine should be in switch on condition and above or below that wind speed, fuel cell should be switch on immediately so that purpose of continuous supply can be maintained [3].

As control philosophy plays an important role in this small micro-grid, it should be able to decide which source should be in service or it need to shift on grid at a particular time. At the same time manual operation to switch on grid power should also be available so that maintenance of the semiconductor parts can take care in atmosphere like India. The wind range should be wide enough to take-care of this situation so that fuel cell cut-in time can be minimized and in a way economical output can be achieved. In this model wind speed is taken from 6–18 m/s to investigate performance of the system [4]. Fuel cell is also capable to deal with 100 kW load. In hybrid system proper control strategy is incorporated to take-care of 24 × 7 availability of power in a village.

Step by step all possible causes are tested for formulated control strategy and during each compilation necessary graphs are captured.

4.0 MODEL OF INTEGRATED MICROGRID

It is clear that when wind speed is below 6 m/s and more than 18 m/s the unit will not serve the purpose. To run the system on fuel cell only is also un-economical. Integration of both of them leads to quantitative and qualitative supply all the time to the load. Figure 1 shows integrated micro grid model consist of wind generator, fuel cell and VRU.

This integrated unit is having control box which decides which energy source needs to put in service for economical as well as availability aspect. Control box also ensures the stable DC voltage availability at DC bus while wind turbine is not available due to scarcity of wind or abundance of wind [5].

This unit is also equipped with reverse blocking diode unit in reverse biased condition so that DC voltages of both source can connect in suitable condition only and feed the load accordingly.

Control system is having three different logic blocks.

1. Control box
2. Under voltage logic
3. Maintenance by pass switch logic

All three parts are described in detail as follows.

4.1 Control box

Main function of this control box is to decide which source to keep in service in hybrid energy system. It decides from wind speed and DC bus voltage value. As per logic first priority is set for wind turbine as it is more economical for operating cost in case of fuel cell.

In logic wind speed sensors and DC bus voltage value sensors provide a value which is being compared by comparators continuously. These comparators give a command when value is goes out of set value. These signals are being gathered at "OR" and "AND" gate to create a logic for switching operation of particular energy sources. Figure 2 shows the control logic diagram.

4.2 Under Voltage Logic

In case of non availability of both energy sources, this logic will come to serve and it will

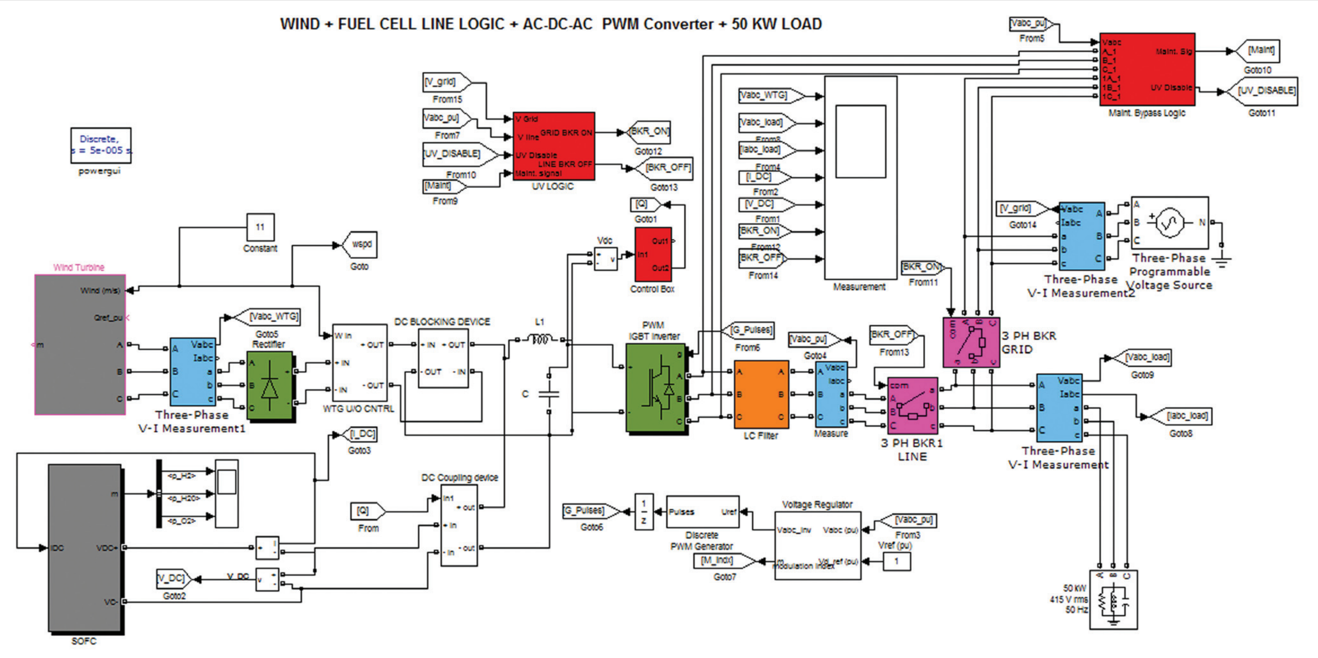


FIG. 1 INTEGRATED MICRO-GRID MODEL.

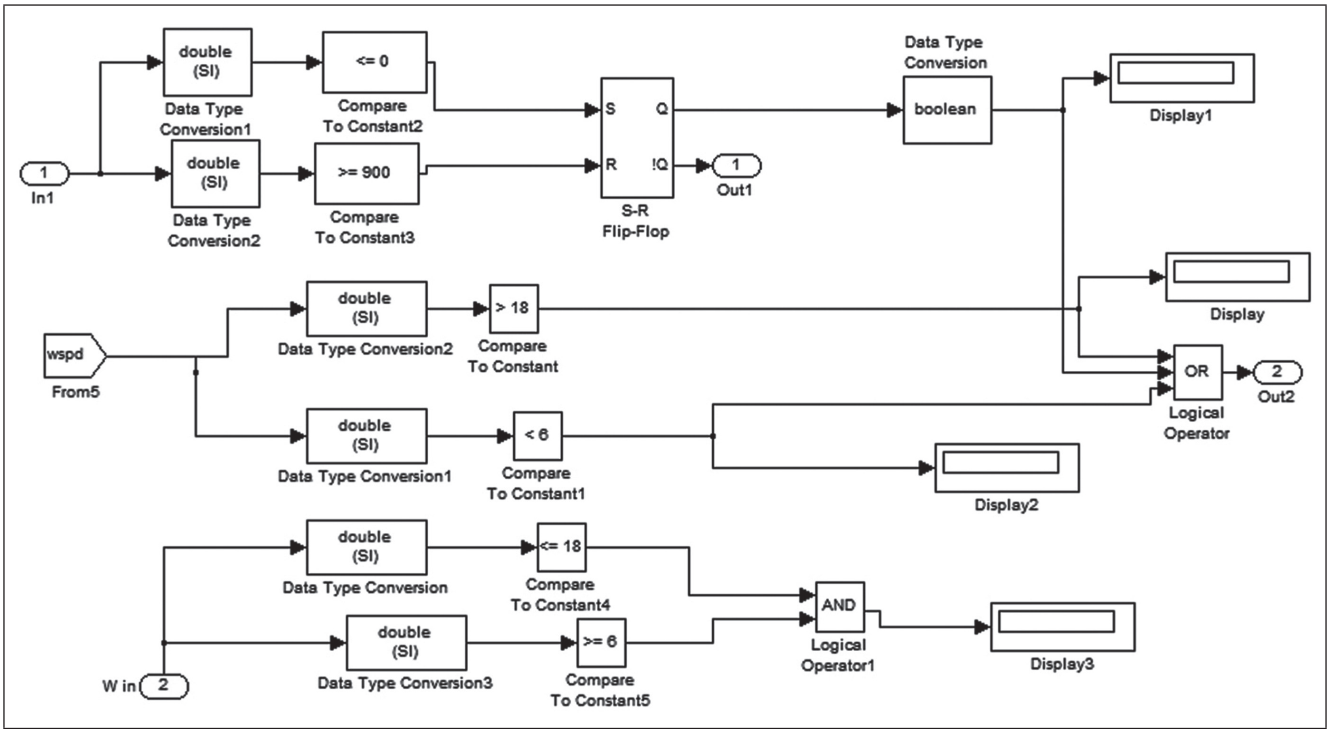


FIG. 2 CONTROL BOX LOGIC DIAGRAM.

immediately switch the system on grid voltage. Figure 3 shows the detail logic diagram. In this logic on-delay timer is set at 40 m/s for actual sensing for non-availability of voltage. It actually sense the voltage value 0.7 per unit value or greater for healthiness of voltage in system [6]. Proper value can be set as per site environment. In this under voltage logic, grid voltage and energy source voltages are being sensed by voltage sensors. Absolute value of voltage is compared with particular value and this signal is fed to an on-delay timer. If this signal remains high for set value of 40 m/s than it will give high pulse, which fed to an AND gate. Same way grid voltage is also sensed and compared to check value is greater than 0.7 per unit value. This signal is logically OR as well as AND to formulate a proper logic for switching of grid and line switching of grid

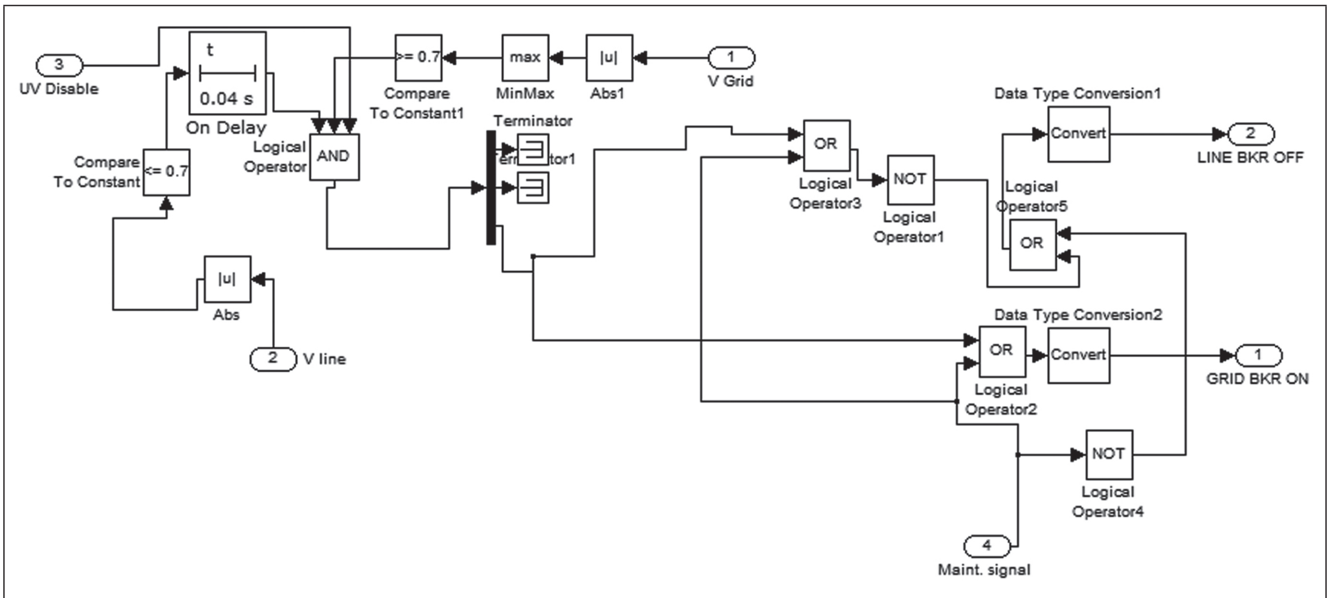


FIG. 3 UNDER VOLTAGE LOGIC DIAGRAM.

and Line breaker at a particular time and also take care the operation of maintenance by pass switch.

4.3 Maintenance bypass switch logic

In case of maintenance for any energy sources, this logic will allow system to switch on grid without any break at load side. Figure 4 shows the detail logic diagram. In this logic, all three phases' voltage values, respective angles and frequency of both sources are measured and compared with pre-set value [7]. If this fundamental requirement of synchronization allows system to transfer the load on grid than only the breaker will operate and load is transferred on grid without voltage disturbance at load side. This logic also allows system to set back to energy source from grid with same synchronization logic. This logic ensures human intervention for selection of maintenance by pass switch on grid or on energy source as per requirement.

To generate the logic for maintenance by pass it is mandatory to compare voltage magnitude, angle and frequency values of both side 3-phase voltages, i.e. grid side and energy source side. As shown in Figure 4 all phase values are being fed to fourier block which distinguish the magnitude and angle value for each phases. Now it is separated so same comparator logic is used to formulate desire logical operation by providing proper set point. Same way frequency values are also compared for both sources. These comparator signals of magnitude, angle and frequency are logically AND operated with maintenance by pass switch value to operate the grid breaker in synchronization mode as shown in Figure 4.

5.0 INTEGRATED MICRO-GRID SIMULATION IN MATLAB™ ENVIRONMENT

System is tested for sequential operation respectively for proper wind speed, operation of maintenance switch, restoration of maintenance switch, out of range of wind, and again proper wind speed condition to check actual operation of control strategy. Breaker conditions are captured for verification purpose.

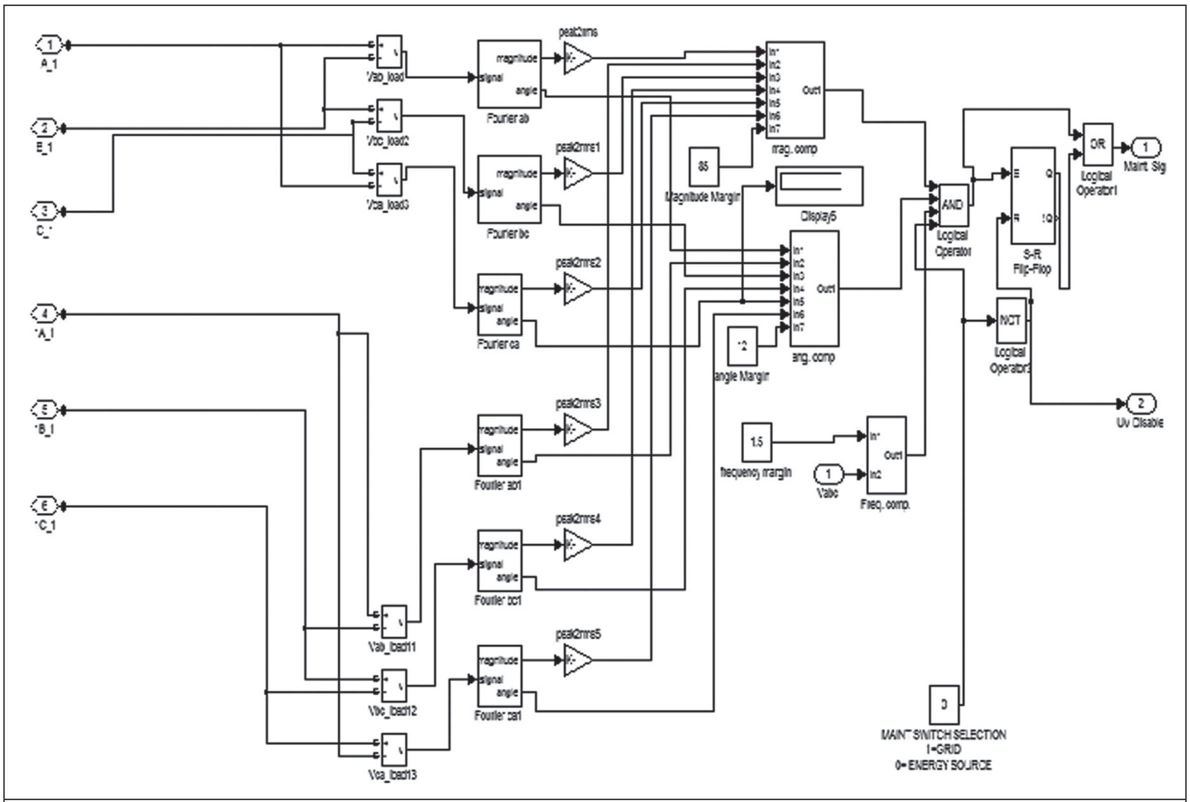


FIG. 4 MAINTENANCE BY PASS SWITCH LOGIC DIAGRAM.

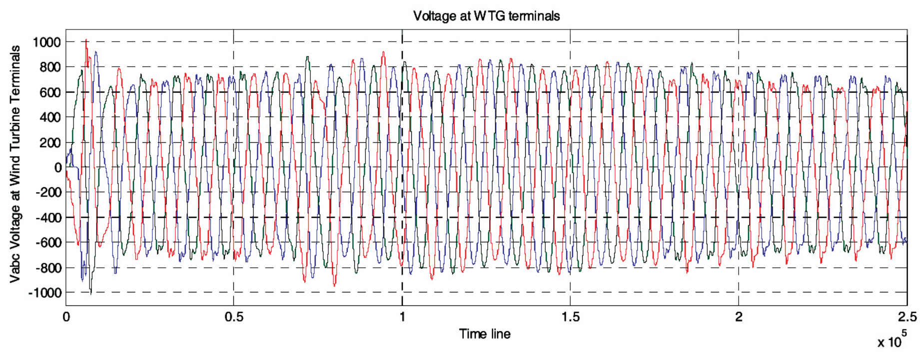
7 nos graphs are extracted as mentioned below [8].

1. V_{abc} Wind turbine at turbine output
2. V_{abc} Load i.e. O/P voltage at load side
3. I_{abc} Load i.e. O/P current at load side
4. I_{dc} i.e. DC current of fuel cell
5. V_{dc} i.e. Voltage of fuel cell
6. Grid breaker status
7. Line breaker status

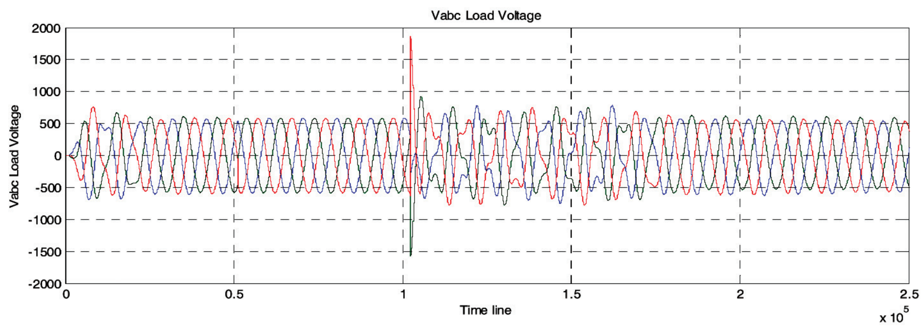
As shown in above graphs, at first instance wind turbine is serving the load while system is made on. Figure 5.1 is of voltage at wind turbine generator terminals. After certain time about 0.5 sec maintenance switch is made on and load is transferred on grid. It can be referred in Figure 5.6 that grid breaker status changed particularly at this point. Minor current fluctuation is also seen in Figure 5.3 which is of load current. Load voltage is almost stable; it can be verified in Figure 5.2, which proves the functionality of synchronization logic.

After stable operation again maintenance switch is made normal and load transferred on fuel cell as wind speed condition is not favorable.

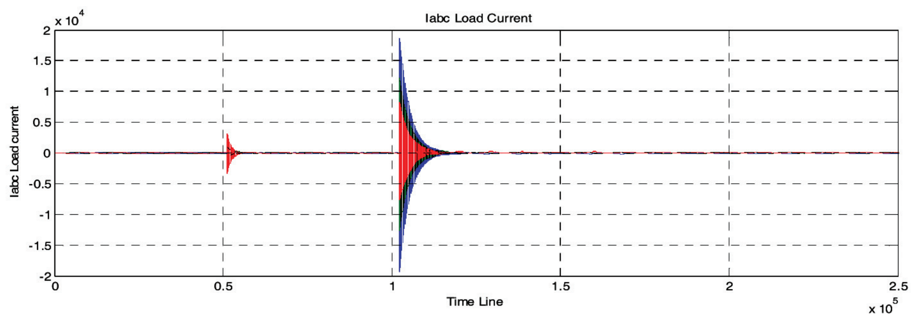
Fuel cell current and voltage values can be verified in Figures 5.4–5.5 respectively. It proves



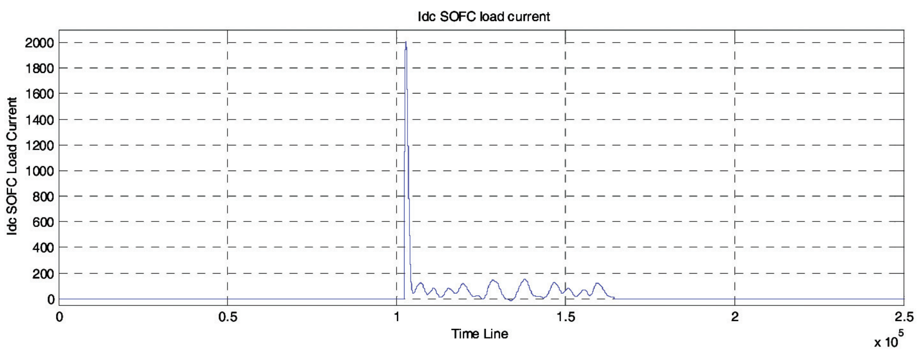
5.1 V_{ABC} WIND TURBINE AT TURBINE OUTPUT.



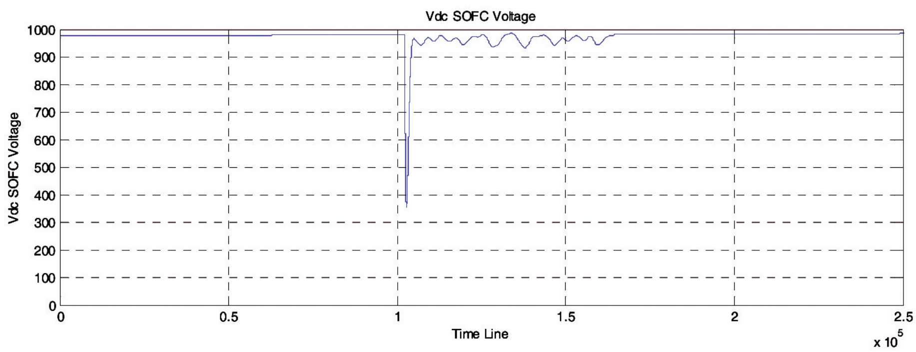
5.2 V_{ABC} LOAD I.E. O/P VOLTAGE AT LOAD SIDE.



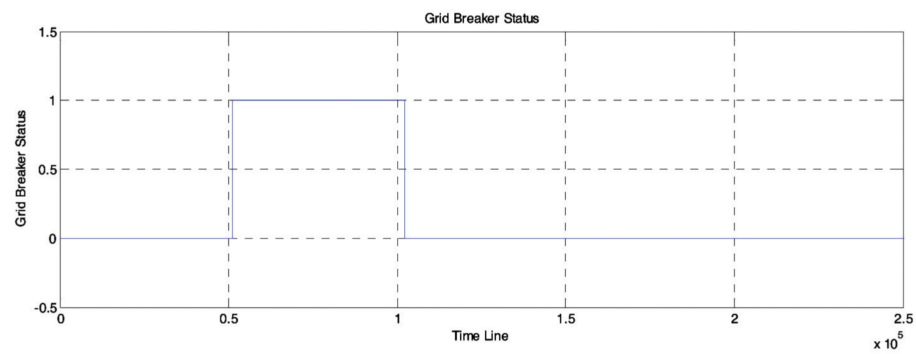
5.3 I_{ABC} LOAD I.E. O/P CURRENT AT LOAD SIDE.



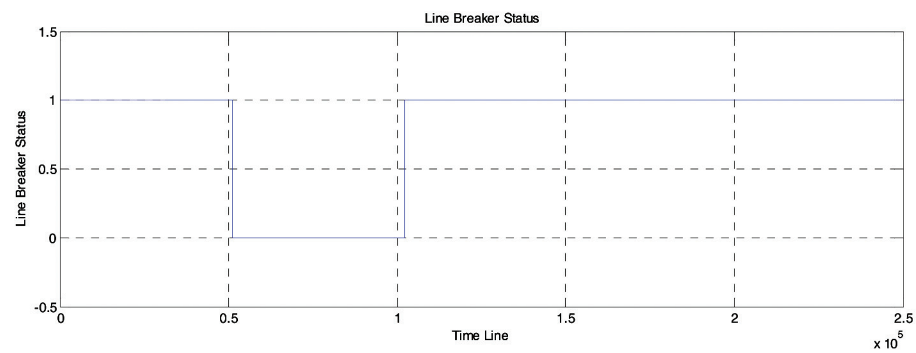
5.4 I_{DC} I.E. DC CURRENT OF FUEL CELL.



5.5 V_{DC} I.E. VOLTAGE OF FUEL CELL.



5.6 GRID BREAKER STATUS.



5.7 LINE BREAKER STATUS.

FIG. 5 SIMULATION RESULTS FOR INTEGRATED MICRO GRID.

that fuel cell is able to serve the load at any time in non availability of wind. Now to check last functionality, wind speed comes to favorable range and as the system is design to prioritize the wind turbine generation it automatically switched on to the wind turbine which can be again verified from SOFC load current value which become zero after 1.5 sec in Figure 5.4. These different operations prove the functionality of control strategy (Figure 5.7).

6.0 OPTIMIZE CONTROL STRATEGY

As shown in Figure 6, dark green colored blocks of lookup table, sub-system, summation, constant, comparator and OR gate are integrates the optimized output strategy for the system. 500 V DC value is supplied by constant block to summation block and it is being subtracted from the micro-grid DC bus voltage value. As value moves towards positive range mean now DC bus is having enough voltage which can be utilize to cater the grid power requirement. In lookup table predicated values are inserted to feed the grid power requirement. Values are fed in slabs of 50 for DC bus values and corresponding grid power in per unit requirement starting from 0.1 and in incremental slab of 0.1 for each 100 V DC bus improvement. 50 kW power is considered as base value at 440 V for all references.

System is simulated and graphs (Figure 7) are extracted for active power of micro grid and infinite bus or utility grid system.

7.0 CONCLUSION

This paper introduces the concept of micro-grid operation to enable electrification of villages in grid environment placed through economical energy sources like the wind and fuel cell. The vision behind the proposed concept is to formulate the economical control strategy for electrification of weak grid villages in islanded as well as grid connected mode. This paper proposes the control strategy of two sources of micro-grids in grid connected mode. The studies are carried out in time domain using the MATLAB™/Simulink™ software. The study confirms practical installation of wind-fuel cell based micro-grid for on-grid electrification for villages.

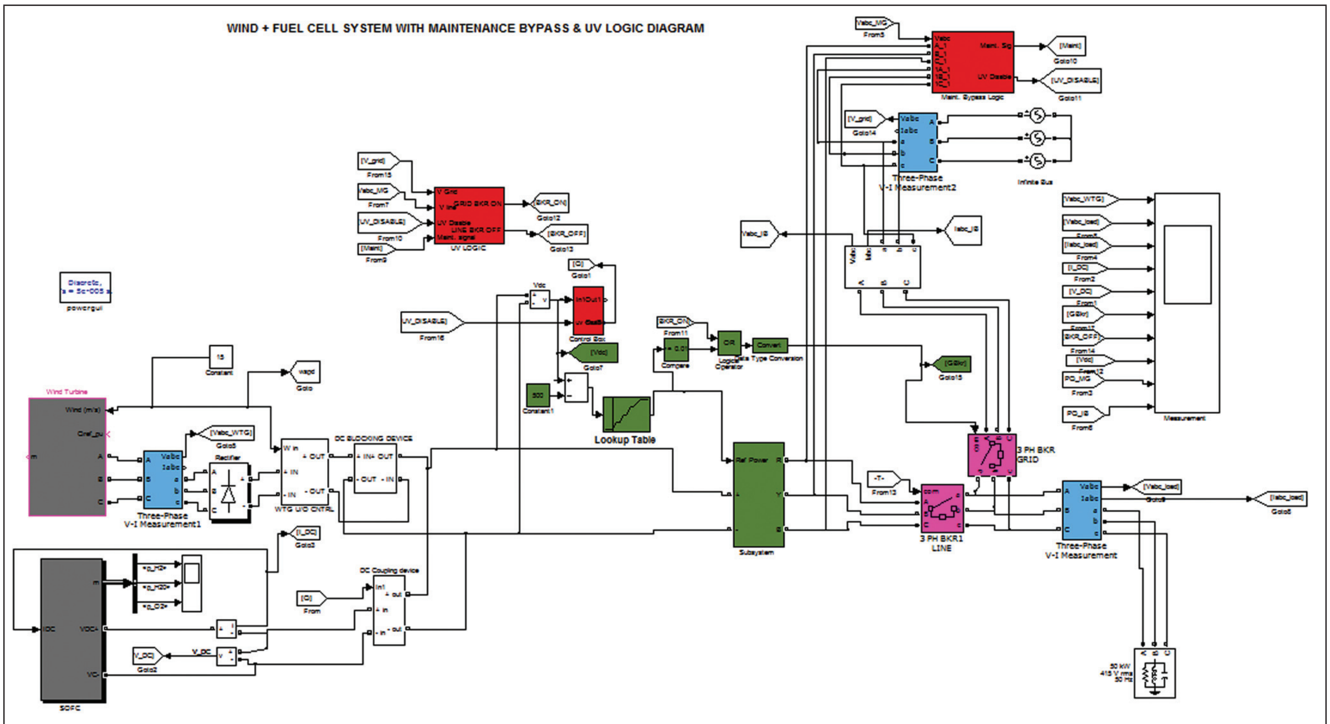


FIG. 6 OPTIMIZED OUTPUT STRATEGIES FOR ON-GRID ELECTRIFICATION SYTEM.

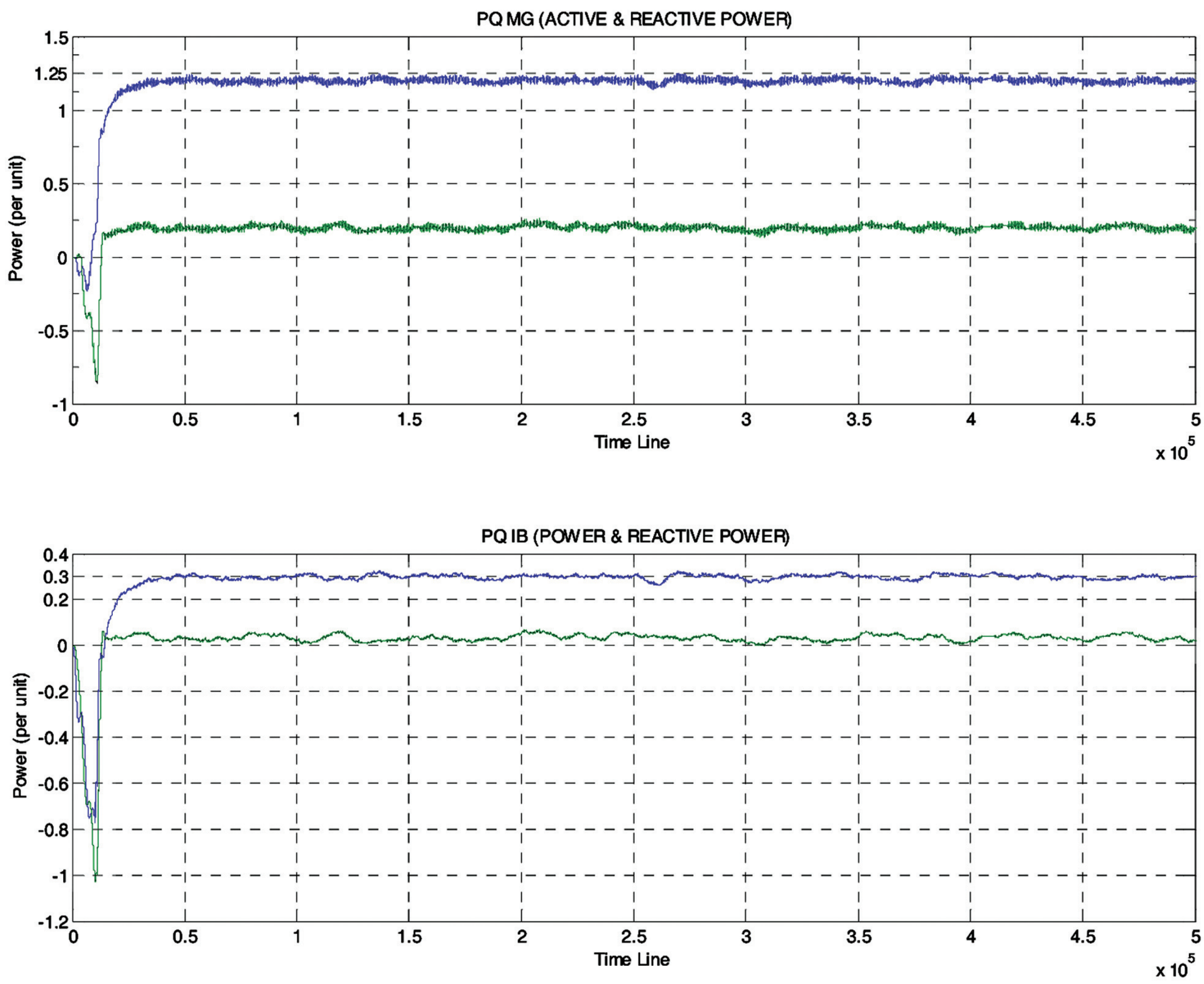


FIG. 7 SIMULATION RESULTS FOR OPTIMIZED STRATEGY.

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