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OPERATION OF A TELECOMMUNICATIONS POWER SYSTEM WITH A NOVEL TOPOLOGY MULTIPLE INPUT BUCK BOOST CONVERTER AND LOCAL MICRO SOURCES

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ABSTRACT

This paper represents a grid connected operation of a telecommunication power system with a multiple input buck boost converter. The multiple input buck boost converter is a new topology, and it act as the interface between the micro sources and the dc bus. The local micro sources used for supplying energy to the telecommunication power system are proton exchange membrane fuel cell and the micro turbine. The main advantages of the proposed power plant are eliminating dc generator, batteries and the automatic transfer switch. The common dc bus of the system is also connected to the distribution network to supply the excess power to the grid by using an inverter. For eliminating high frequency switching oscillations, selected harmonics and higher order harmonics, LC filter, double tuned filters and C type high pass filters are used respectively.

Index terms – telecom power system, micro turbine model, fuel cell power plant model, multiple input converters, parallel operation.

I. INTRODUCTION

The main important components of conventional telecommunication power systems are grid, diesel generator, batteries, and an automatic transfer switch. These systems use the ac bus as the main bus and connect the grid and the diesel generator to the main bus by using a transfer switch. This conventional system relies on the diesel generators and the batteries to provide uninterruptable service during a long power outage. During the power outage, power is temporarily supplied to the critical loads through batteries, and the automatic transfer switch will switch to the diesel generator. A typical telecommunication system has ac noncritical loads, ac critical loads, ac ultra- critical loads, and dc critical loads [1].

It is proven that the telecom power system with the diesel generator and grid connection with a battery backup system is a reliable telecommunication power plant, but there are some drawbacks in this system [1]: 1) the automatic transfer switch is a single point of failure in the system. The diesel generators which are equipped with two starters are reliable, but they require frequent and costly maintenance; 2) in addition, diesel generators are the source of pollution and noise; 3) a battery bank with long backup time requires space; considering replacement and maintenance, battery banks are some of the most expensive equipment in telecommunication systems. Battery banks are needed to be replaced in every five years and they will occupy a large area [2]. Considering replacement cost, the area that the battery bank occupies and maintenance, they are one of the most expensive and bulky pieces of equipment in a telecommunication power plant.

There are many different methods that try to address these issues and replace the diesel generator and/or reduce or eliminate the battery bank. The authors of [1] proposed a method using a micro turbine instead of a diesel generator and reducing battery reserve time. In this method, the battery reserve time is reduced to 10 min to provide the capability to restarting micro turbine three times in the case that the starting process fails. The main advantage of this architecture is eliminating the diesel generator and automatic transfer switch and battery reserve time is also reduced to 10 min. but the drawbacks are that the main source of power for this system is the utility grid and still the system depends on the battery bank. In [3], ultra capacitors are used instead of batteries. Although this system effectively eliminates the battery, it still needs to rely on diesel generator during long power outages. In addition, in order to reach high energy densities, a great number of ultra capacitor banks are needed.

In [4], instead of batteries and the diesel generator, ultra-capacitors and fuel cells are used respectively. The main benefit of this system is eliminating batteries completely. However, this system uses ultra capacitors and fuel cell only as a backup system which can be considered as a drawback. Since fuel cells are rather expensive right now, the system needs a lot of time for paying back on the investment. Moreover, energy densities of ultra capacitors are lower in comparison to that of batteries. Thus, more ultra capacitor banks are needed in order to provide a sustained power supply for longer periods. In [5], micro sources, such as photovoltaic, fuel cells, and storage devices are utilized in a telecom power system. In [6], micro turbine and fuel cell are coupled to achieve higher efficiency for electrical power generation. Although the MT burns natural gas and FC reformer uses natural gas for obtaining hydrogen, these resources have reduced emissions, and their efficiencies are higher than conventional diesel generators.

Diesel generators produce not only carbon monoxide (CO) and carbon dioxide (CO_2), but also the nitrogen oxides (NO_X), sulfur dioxide (SO_2), some hydrocarbons, and mercury as well as other particulates. The reformation process of methane in the reformer or burning process of methane in a micro turbine only produces CO_2 which is not poisonous. The energy density of natural gas is more than the energy density of diesel fuel. So fuel cells and micro turbines are more efficient.

In terms of fuel efficiency and maintenance costs, one can claim that the operation cost for the FC/MT system is relatively less, due to higher efficiency, considering the operating costs (fuel and maintenance expenses). Most of the fuel cells require near-zero maintenance and need only annual inspection periods. On the other hand, micro turbines are more reliable than conventional diesel generators and have less failure chances. Therefore, considering these issues and the fact that the batteries and standby diesel generators with the necessary air conditioning systems are the maintenance required components of a telecom power system, it can be stated that the proposed architecture is more cost effective than the conventional telecom power systems. In the proposed system a fuel-cell power plant and a micro turbine are employed as the main power sources and connected through a multiple input converter. Moreover, the dc bus voltage is converted to the ac voltage for grid interconnection along with the required harmonic and switching noise suppression filters.

II. PROPOSED ARCHITECTURE

The proposed system, not only are micro sources used as backup systems during the power outage, but they are also used for normal operation. This method reduces the investment payback time for micro sources. Some benefits of the proposed architecture are eliminating the transfer switch, eliminating the diesel generator, and eliminating the battery bank. Another benefit is that the critical and noncritical telecommunication loads are all connected to the main bus. This system supports all of the load types (ac noncritical, ac critical, ac ultra-critical, and dc critical) with high redundancy and high reliability such that none of these loads experiences the power outage. This system can also be connected to grid through a dc/ac inverter for higher reliability and efficiency in the case that one of the micro sources goes out of service. Furthermore, the grid connection can be used to supply the additional power generated by the fuel cell and micro turbine.

In the proposed system, the micro sources used are micro turbine (MT) and fuel cell (FC). Most micro sources, such as fuel-cell power plants, have a long response time which is in the order of seconds or minutes. In order to compensate for their slow response time, some sort of energy-storage device with a fast response time, such as an ultra capacitor (UC), is needed. The UC needs to store power for only a few minutes. Some benefits of the UC are their wide range of operating temperature, long life, and superior performance.

Proposed power system architecture is shown in Fig.1. In this system, each micro source can supply the necessary power for the load. Thus, even when one of the micro sources goes out of service, the other micro source can provide the load without any interruptions. The probability of unavailability of all Micro turbine, Fuel Cell, and utility grids all at the same time is close to zero with the exception of natural disasters. This architecture is very robust, reliable, and provides uninterrupted power to the load. This architecture can also be used in places where utility power is unavailable.

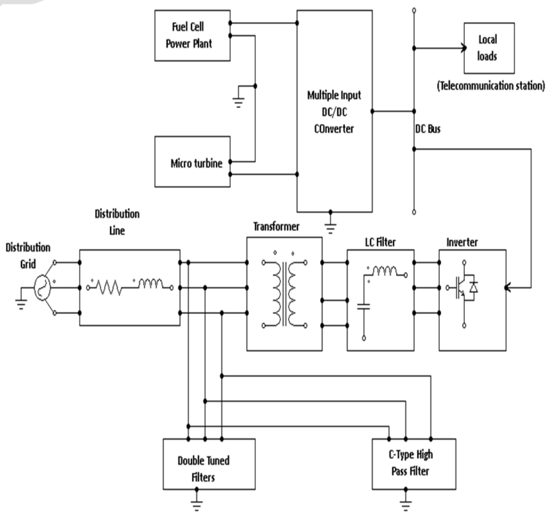


Fig. 1. Proposed telecommunication power plant with a novel multiple input buck–boost converter and grid connection.

The micro sources supply power in parallel to each other in order to meet the telecom power requirement. Since the telecom power system requires high availability and reliability, each input source is oversized; therefore, in case of a failure of any of them, the other can meet the overall telecom power requirements. The grid interconnection is also provided in this study. When there is no failure from input sources, not only do they supply power to the telecom station but they also inject power to the grid. In the case of a failure in one of the power sources, the other source can supply power to the system. On the other hand, in the case of the failures of two input sources or partial damage of one source when the other is totally down, the required power can supplied from the grid.

If required, the PWM switching signals of the dc/ac grid connection inverter are interrupted by a fault detector and controller. In this case, none of the inverter switches are turned on and their anti parallel diodes altogether form a three-phase diode bridge rectifier. In this way, the required power is automatically supplied from distribution network to the telecom dc bus through the ac/dc rectifier. Therefore, the inverter is capable of bidirectional operation, which improves the sustained availability of the telecom power system.

The proposed architecture for telecommunication power systems in this study uses the dc bus as the main bus. The reason behind using a dc bus is that most of the micro sources have dc output voltage and they can easily be connected to this bus through a dc/dc converter. While micro sources are connected to this bus through dc/dc converters, the grid can also be connected through an ac/dc rectifier. There are three different commonly used possible nominal voltages for this dc bus (48 V, 150 V, and 300 V). In the conventional telecommunication systems, 48 V is used. 300 V is chosen for the dc bus, since it has some advantages, such as higher system efficiency, less conductor losses, lower system cost, lower rectifier cost, and less copper required over the conventional 48 V. The 300-V dc bus is more suitable if there is a need for bidirectional power flow for the utility grid. The load in telecommunication system varies from 3 kW in remote telecom systems, up to 250 kW and higher in large telecom centers. The designed power plant in this study has a power rating of 22.5 kW. This topology can easily be applied to other telecom systems by changing the size of fuel-cell and micro turbine accordingly.

III. MULTIPLE- INPUT BUCK-BOOST CONVERTER

To connect all of the micro sources to the main dc bus, a new topology multiple-input positive buck-boost (MIPBB) converter is used. Multiple-input converters can combine different energy sources with different current and voltage characteristics and will produce single output. There are many different multiple input converters available. Some of the benefits of the proposed MIPBB converter are a low number of parts and positive output voltage without requiring any extra transformers.

Fig. 2 shows the proposed MIBB converter. This converter uses one common inductor and one capacitor for all of the inputs. Another benefit of this converter is that it can accommodate up to different inputs with different voltage and current characteristics. This converter can be used as a buck or buck-boost converter. Here, the buck-boost operation is chosen since the voltage of the micro turbine is higher than the output, and the voltage of the fuel cell is lower than the output. In order to drive this converter in buck-boost mode, S_i (i = 1, 2, 3…N) and Q should be switching at the same time.

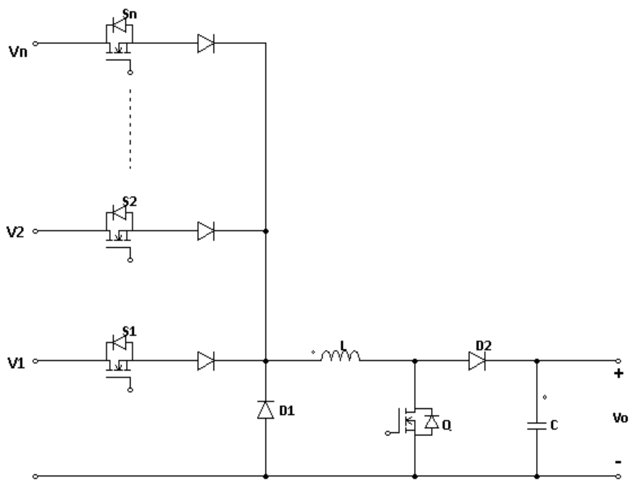


Fig 2. Proposed multiple input positive buck-boost converter topology.

The proposed converter is used here as a two-input converter for the fuel cell and micro turbine sources. Generally, if another micro source or storage device is added to the system, the same topology can be applied by adding one more switch but still sharing the common inductor and the rest of the topology. The operation of two input buck-boost converter can be explained in three different modes. Switch Q is ON whenever one or more of the input switches are ON. Inputs are ordered from low voltage to high voltage ($V_1 < V_2$).

The operation of the MIPBB can be explained as follows. In the first mode S_1 and S_2 are ON. In this mode, the input with higher voltage turns OFF the other switch. Hence, in mode 1, the input with higher voltage V_2 is conducting. In the second mode, switch S_2 turns OFF; therefore, in mode, the lower voltage input V_1 is conducting. In mode 3, $S_1$and S_2 are turned OFF and in this mode, $D_1$and D_2 are turned ON. With this switching strategy, each switch has a duty cycle and an effective duty cycle. For S_2, the duty cycle and effective duty cycle are the same while for S_1, the effective duty cycle is

$$D_{eff} \quad D - D \qquad (1)$$

Based on (1), D1 should be greater than D2 to transfer power from the first input to the output. If the number of inputs is increased to to more than two, the equation for effective duty cycle becomes

$$D_{eff} \quad D - \sum \quad D_{eff} \qquad (2)$$

The number of inputs can be increased if $D_1>D_2>.......D_N$ and the input voltage levels are selected as $V_1< V_2<......V_N$.

The output voltage of the Multiple Input Buck Boost Converter for the operation in buck-boost mode is defined as

$$V_{out} \quad \frac{\sum}{\quad} \qquad (3)$$

IV. FUEL CELL AND MICROTURBINE MODEL FUEL CELL

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. It has higher efficiency than conventional power plants [8]-[10]. Fuel cells are environmentally friendly (environmentally clean), have extremely low emission, and produce very low noise [8]. Fuel cells are composed of the fuel-processing unit (reformer), the fuel-cell stack, and a power conditioning unit [10]. Hydrogen is produced in the reformer by processing any hydrocarbon fuel [8] such as propane, methane, and methanol. This produced hydrogen is supplied to the fuel-cell stack. Using provided hydrogen and oxygen from the air and through the electrochemical process, the fuel-cell stack produces electricity and water.

Due to rapid start up time and low operating temperature, proton-exchange membrane fuel-cell power plants (PEM FCPPs) are best choice for telecommunication power systems. There are two mature fuel-cell technologies, such as PEMFC and SOFC; PEMFC is preferred due to its advantages over the SOFCs. PEMFCs have greater power density than SOFC which results in the overall size reduction. Besides, they have much faster start up (warming-up) time and they have faster dynamic response.

SOFC's need extremely high operating temperatures than PEMFCs such as 800 -1000 . This may also cause damage to the components due to thermal stress during the operation and even manufacturing [11].

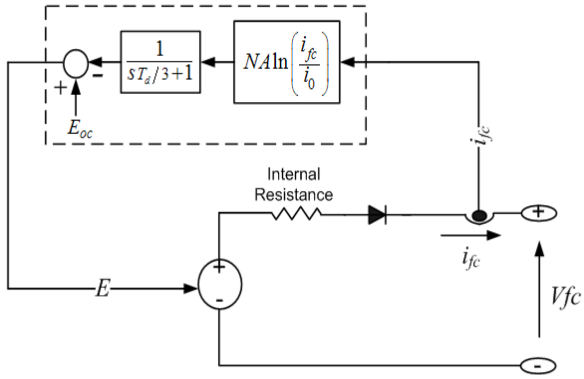


Fig 3. Fuel cell model

A model for 27 kW (PEM FCPPs) is developed. The fuel-cell model that is used in this manuscript is developed in MATLAB and Simulink.

$$E_{OC} \quad {}_C E \qquad (4)$$

$$i \quad \frac{z \qquad e^{\frac{\Delta}{T}}}{\quad} \qquad (5)$$

$$A \quad \frac{T}{z\alpha} \qquad (6)$$

Where,

R = 8.3145 J/(mol K)

F = 96485 A s/mol

z = Number of moving electrons

En = Nernst voltage, which is the thermodynamics voltage of the cells and depends on the temperatures and partial pressures of reactants and products inside the stack (V)

α = Charge transfer coefficient, which depends on the type of electrodes and catalysts used

PH2 = Partial pressure of hydrogen inside the stack

(atm)

PO2 = Partial pressure of oxygen inside the stack

(atm)

k = Boltzmann's constant = 1.38 × 10–23 J/K

h = Planck's constant = 6.626 × 10–34 J s

ΔG = Size of the activation barrier which depends on the type of electrode and catalyst used.

T = Temperature of operation (K)

Kc = Voltage constant at nominal condition of operation.

MICRO TURBINE MODEL

The main components of a micro turbine are the compressor, combustion chamber, and a turbine. The operation principles of a micro turbine are similar to a steam turbine. The air after being compressed in compressor forms a combustible mixture by getting mixed with the injected fuel. The mixture is ignited in the combustor to produce heated air. Then, the heated air is expanded in turbine to drive the turbine [8]. There are two major types of micro turbines: 1) single shaft and 2) split shaft [14], [15]. In the single shaft, the micro turbine electric generator and turbine are mounted in the same shaft. With the split shaft micro turbine, a gear box is used to couple the electric generator to the micro turbine. The model is developed for a 37-kW, 300-V micro turbine [8].

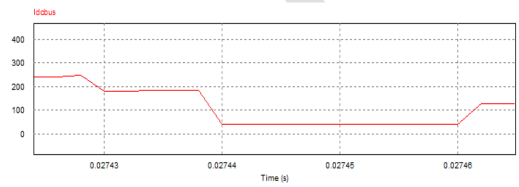
V. RESULTS AND DISCUSSIONS

The configuration shown in Fig. 1 is used for the analysis of the proposed system. Fuel cell (FC) and micro turbine (MT) are used as two input sources for the multiple input positive buck-boost (MIPBB) converter. The inductance of MIPBB converter is 2 H and the capacitance is 5 mF. The switching frequency is 50 kHz. The system is designed for the load of 22.5kW. For grid interconnection, an LC filter, double-tuned filters, and a C-type high-pass filter are developed for eliminating high-frequency switching oscillations, selected harmonics, and high-order harmonics, respectively.

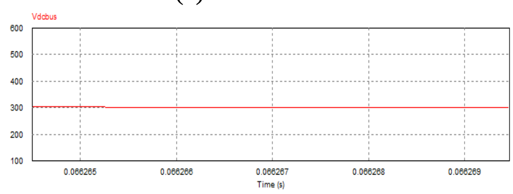
For using as a backup source in discontinuous mode of operation, fuel cells are the best suitable power generation unit. In this telecommunication power system, since the generation units are oversized for high reliability, the micro turbine can be considered as the main source while the fuel cell can act as a backup source to be operated when needed, particularly during maintenance and repairs or during overloaded conditions. The parallel operation and load sharing capabilities of the PEMFC and MT units is utilized by the proposed MIBBC.

The simulation of the proposed power plant was done by using PSIM software and the results of the simulation shown in the figures given below.

Fig 3 shows the current, voltage and power of the dc bus which is connected to the output of the multiple input buck boost converter. Fig 4 shows the excess power feeding to the grid after the utilisation in the telecommunication power plant, inverter output voltage and the grid voltage respectively.



(a)



(b)

Fig 3.(a) Current, (b) voltage of the dc bus

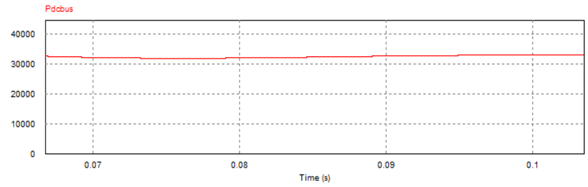
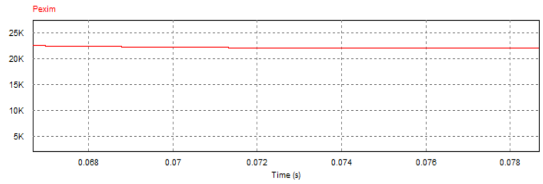
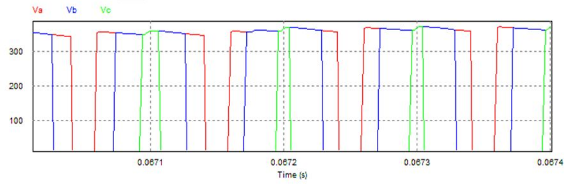


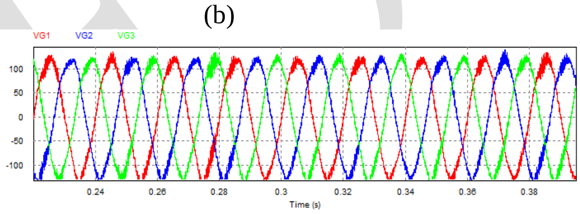
Fig 3 (c) power of the DC bus



(a)



(b)



(c)

Fig 4. (a) Excess power to the grid, (b) inverter output voltage (c) grid voltage.

The fuel cell is simulated by using MATLAB & Simulink Software and the output waveforms are obtained are as follows. Fig 5 shows the fuel flow rate, utilisation, stack consumption, and stack efficiency of the fuel cell. Fig 6 shows the voltage and current waveforms of the fuel cell.

When the load increases, the voltage of the fuel cell is decreased and the current of the fuel cell is increased to pro- vide more power to the load. The reverse holds for a decrease in demanding power due to the fuel-cell current and voltage characteristics. Although the current supplied by the fuel cell is periodically interrupted, the fuel-cell output voltage and hydrogen flow respond according to the average (or mean value) value of this current over a switching period, not the instantaneous value of this current.

When compare with the fuel cell dynamics the switching frequency is very high, so the actual effective fuel cell current is the mean value of the fuel cell current over a switching period. Due to the reformer gas-processing dynamics fuel cell with reformers may have relatively slow response time to load changes and it is not depends on the fuel cell reaction speed.

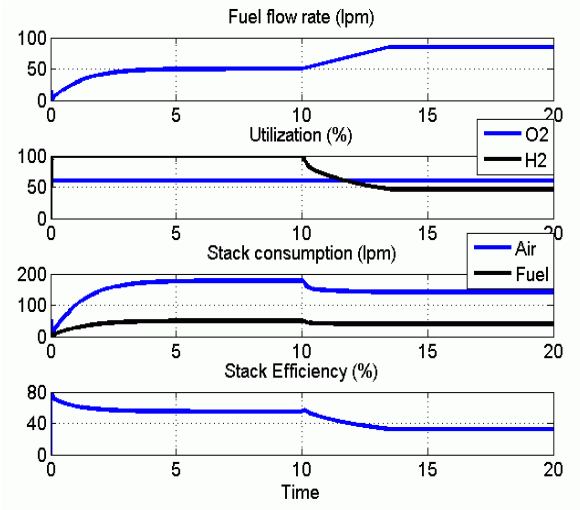


Fig 5. fuel flow rate, utilisation, stack consumption and stack efficiency of the fuel cell

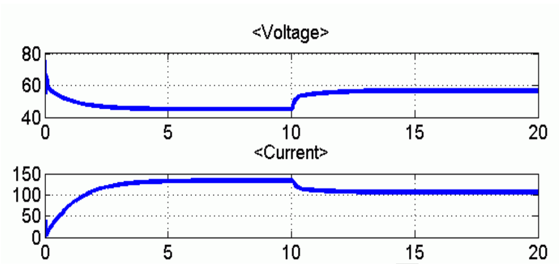


Fig 6. Voltage and current waveforms of the fuel cell.

In this study, it is considered that the required amount of hydrogen and oxygen are directly supplied to the fuel-cell anode and cathode channels. In real-world applications, inter- mediate storage solutions can be used to avoid the slow fuel processing effects of reformers.

VI. CONCLUSION

A new topology multiple-input positive output buck boost dc/dc converter has been introduced in this paper for utilizing micro sources. The micro sources used in this paper are micro turbine and fuel cell. This converter is used to connect multiple inputs with different voltage and current characteristics to a single output. Modelling of PEM FC and MT was described. Besides, the topology, operating principles, and control system of a multiple-input positive buck-boost converter were introduced. The telecom station is powered by the proposed topology. Furthermore, using a dc/ac inverter and appropriate filters, the proposed topology is connected to a distribution network.

Detailed analytical and mathematical modelling, design, and analysis are presented. According to the results, the system presented an excellent response in meeting the power requirements of a telecom system. The presented results show that the proposed topology is an enabling technology for future telecom power systems, and this study addresses the grid interconnection problems for micro sources and/or renewable energy systems.

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