Power electronics and control of a four inputs hybrid power system

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Abstract- **A hybrid power system consists of two or more power sources working in parallel. Such a system needs power electronics to extract maximum power and to control the flow of power from each renewable power source to the users load. We consider a small hybrid power system consisting of two wind turbines, a PV array and a pico-hydro system. A parallel combination of DC-DC converters connected between renewable energy sources and a common DC bus is used to control the power flow in the hybrid power system. In this paper we present a power electronic and control solution for such four inputs small hybrid power system with a common 48V DC bus. System power electronics design and proposed control strategies for each renewable power inputs are presented. Design and development progress of the proposed power electronics and control arrangement is included in the paper.**

Index Terms—Hybrid Energy System, Multi-input converter, supervisory controller.

I. INTRODUCTION

Applications of renewable energy have increased significantly during the past decade. Hybrid power systems employing two or more renewable energy sources are the best option for many remote and grid connected sites. Such systems need power electronics and control arrangement to extract maximum power from the available renewable energy resources and deliver a reliable power to the user load. Hybrid power system power electronics is basically a number of power converters working in parallel. Each converter in such an arrangement has its own PWM controller. In addition to that there is a system supervisory controller that takes system measurements and control power flow with in the system. Supervisory controller can also log system performance data and take commands from a remote dispatch center.

Different circuit topologies for multi-input dc/dc converters and control algorithm have been proposed to combine different types of clean energy sources to obtain regulated dc output voltage. Different dc sources can be put in series [1, 2] or can be paralleled [3, 4] by using coupled transformer to achieve desired load voltage. The control strategies for paralleled dc sources are based on time sharing concept. So some references [e.g. 5,6] on multi-input converters are available which are based on the concept of the transformer flux addition, and converters delivering power individually and simultaneously. But such an arrangement requires four switches in each input side converter.

The hybrid energy system that is considered here is comprised of two wind turbines, one photovoltaic module and one micro hydro. The battery is considered as storage for the system. Figure 1 shows the basic block of the proposed hybrid energy configuration.

The objective of this paper is to propose a multi-input dc-dc converter and simulate the topology in MATLAB simulink environment. This paper also describes the proposed control strategies for hybrid energy system.

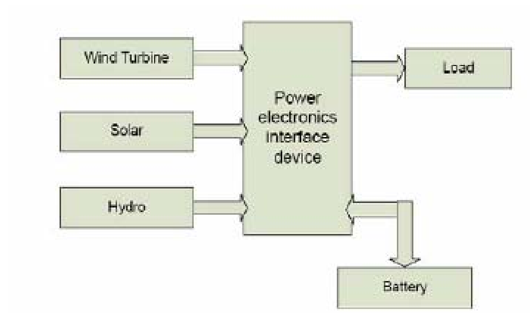

Figure 1: Basic block diagram of the system

II. CONVERTER TOPOLOGIES FOR MULTI-SOURCE HYBRID POWER SYSTEM

A multi input (MI) power converter is a practical example which can be used for accommodating multiple sources. With multiple inputs, the energy source is diversified to increase the reliability and utilization. The basic difference between parallel operation of the single input converter and multi input converter is shown in figure 2. A multi-input converter accommodates all the inputs whereas in parallel operation separate converters work in parallel.

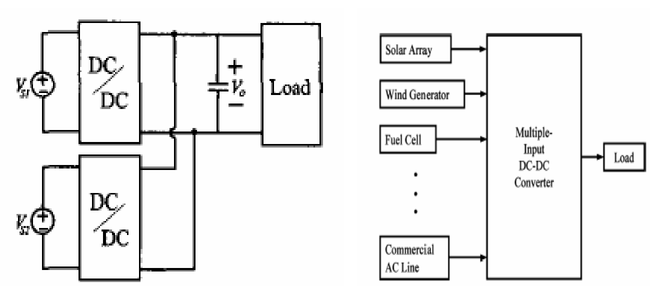

Figure 2: Basic configuration of parallel operation of converters and MI converter

Though this concept of multiple inputs in one converter is new, it has gained acceptance in a couple of fields like hybrid electrical vehicle and renewable energy system.

Generally, the paralleling of power converter modules offers a number of advantages over a single, high-power, centralized power MI converter. Paralleling of standardized converter modules is an approach that is used widely in distributed power systems. A desirable characteristic of a parallel supply system is that individual converters share the load current equally and stably. Parallel modules are usually not identical due to differences in power level in each power stage and control parameters.

III. Multi-port Half Bridge Converter

The proposed half bridge converter for multiple input configurations is same as half bridge converter [figure 3]; but it has multiple input sides and one output. The configuration is shown in figure 4. It consists of two input-stage circuits, a three winding coupled transformer, and a common output-stage circuit. The number of the input-stage circuit can be increased to number of input dc sources

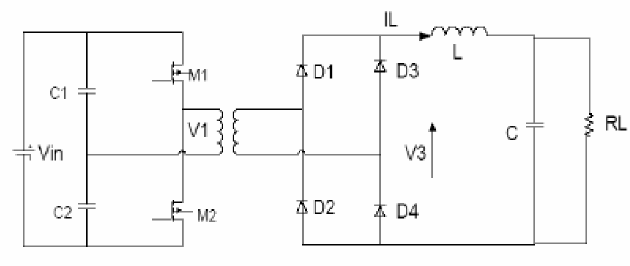

Figure 3: Half bridge push-pull converter

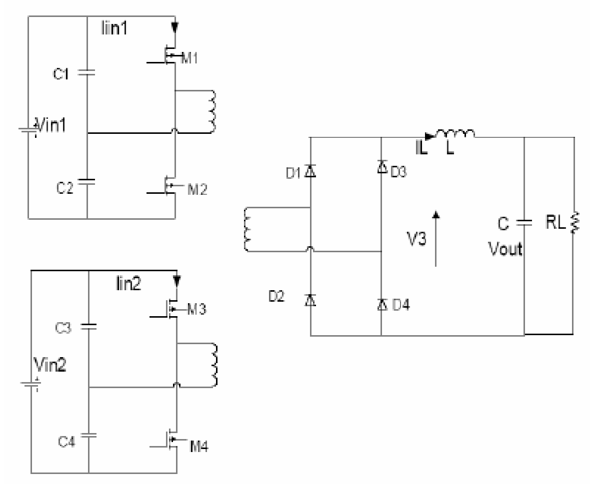

Figure 4: Multi-input half bridge converter

requirement while the output-stage circuit remains unchanged. The operation of multi-input half bridge converters are similar to the single stage half bridge converter while all the input sources are working at same duty cycle. In order to explore more the half bridge multi input converter, simulation has been carried out in Matlab-Plecs environment. Detailed study of the simulation is given in the next section.

IV. Simulation Results

Half bridge multi-port dc-dc converter is simulated for different configurations and in different cases. The control variables in multi-port dc-dc converter are the duty cycle of each input-stage. The converter can operate either in same duty cycle for each input stage or in different duty cycle for each input stage. Case1 is the situation when all the input stages are operating at same duty cycle but in case2 each input stage is running at different duty ratio. In the plots (figure 5, 6, 9, 10), the current is in amp and x-axis is in time with units in seconds.

For simulation study, input voltage of source #1 is considered to be 48 volts, for second source- input voltage is 24 volts, the output voltage is 24 volts and the power rating for this converter is 400 watt.

Case1: Both input-stages of the converter are operating at the same duty cycle and frequency.

Figure 5 shows the simulated result of case1. The result shows the currents of each input stage and output circuit. Here both the input-stage shares power equally. In this case M1 and M3 are turned ON and OFF at the same time where as M2 and M4 are switched ON and OFF at the same time. No feedback is present in this case.

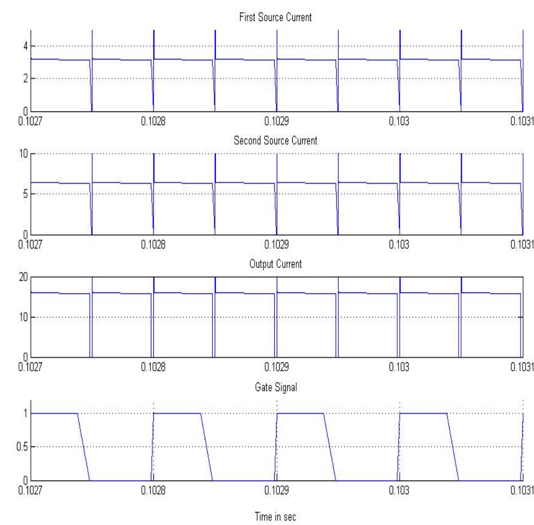

Figure 5: Simulation results of MI half bridge converter (case1)

Figure 5 is the current wave shape for different stage with gate signal for M1. Here 48% duty cycle is considered.

Case 2: Both input-stage of the converters are operating at different duty cycle

In a practical situation both the input-stage cannot run at the same duty cycle all the time. (say two renewable sources are producing power at different level. Power output of source 1 is more than power output of stage 2) In that case MI converter input-stage 1 will be on for more time than input-stage 2. And in this case power is feedback to input stage 2 from input-stage 1. Voltage induced in secondary winding is more than the voltage induced in primary winding of input-stage 2. As a result negative power flows will occur in the input-stage 2. The simulated result is shown in figure 6.

The induced voltage on each winding of the coupled transformer is clamped to the value that is proportional to the output stage. Figure 6 shows that during off time of the input-stage 2 power is fed back to input stage 1 as well and as the

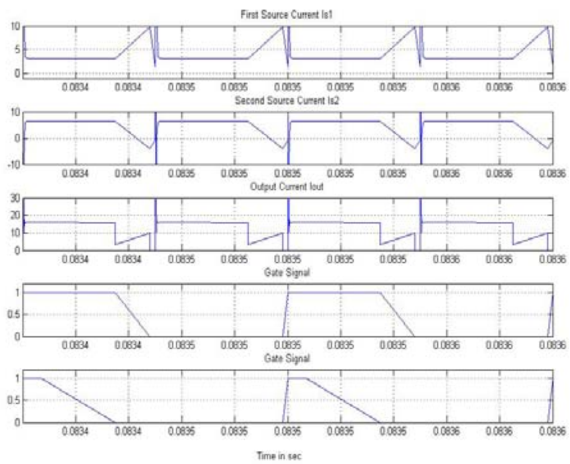

Figure 6: Simulation result –currents for case2

direction of the source current and feedback current are same, so current is adding up in input stage 1.

V. Half Bridge Dual Converter

As described above, in a half bridge multi-input voltage source converter, power feedback occurs in different input stages. To overcome this problem of power feedback we could add diode in series with each switch which blocks the free wheeling path for the circuit. Another option is current source half bridge multi-input converter topology for the system. Applying the duality principle to the transformer-coupled half-bridge push-pull voltage source converter, the current source converter is developed [7] and is presented in figure 7.

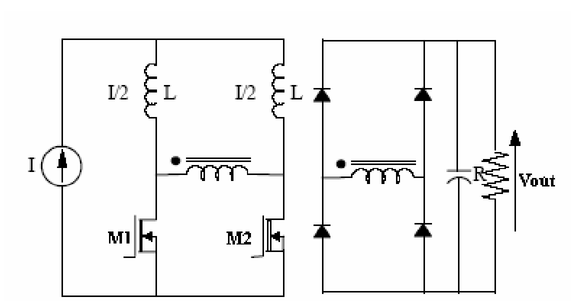

Figure 7: Dual of the half bridge converter

The attributes of the current source converter are derived from the voltage source converter using the dual principles as follows:

- The half bridge voltage source converter (shown in figure 3) uses two *capacitors* to divide the supply voltage into two equal half. Alternate *closures* of the switches apply either +Vin/2 or –Vin/2 *across* the transformer primary. The dual converter (shown in figure 7) uses two *inductors* to divide the available supply current into two. Alternate switch *openings* direct either +I/2 or –I/2 to flow *through* the primary.
- At least one switch is *open* at all times in the half bridge voltage source converter. In its dual, at least one switch is *closed* all the time in the current source converter.
- The *closure* of both switches is destructive for the half bridge voltage source converter, causing a *short circuit* of the *voltage source* input; in the dual converter *opening* both switches is destructive, causing a *open circuit* of the input *current source*.
- The half bridge voltage source converter is *buck* derived, where as the dual is *boost* derived.
- The output rectifier stage in the half bridge voltage source converter uses a *current stiff inductive* filter. The dual filter in the current source converter uses a *voltage stiff capacitive* filter.
- While the half-bridge voltage source converter is suited to higher DC bus *voltages*, the dual converter is suited to higher DC bus *currents*.
- When both switches in the voltage source converter are Off the converter is in free wheeling stage and when any of the switches is Off it is in power transferring stage. In the current source converter, when both the switches are ON, the converter is in free wheeling stage and when any of the switch is ON it is in power transferring stage.

For multi-input configuration of the half bridge current source converter, the output stage remain the same only one or multiple input stages are added to configuration and is shown in figure 8.

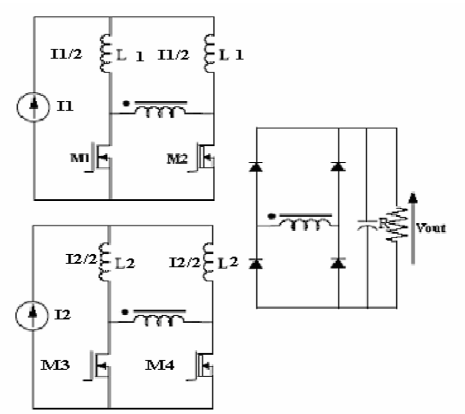

Figure 8: Multi-input current source half-bridge converter

VI. Simulation Results of Dual Converter

Case3: Switches are operating at the same duty cycle

As the converter is operating at constant duty cycle and same for both the source, the load is equally divided between the sources. The simulation result is given in figure 9.

The source current I1, is shared equally between the current dividing inductors left L1, and right L1. If M1, is closed, the current flowing in L1, flows into the transformer primary, out of the primary winding and then through M1. This primary current produces a secondary current that is rectified and injected into the output filter capacitor. If M2 is closed, then the current in L1, flows into the primary and then through M2

When both switches are closed, the dual converter is said to be

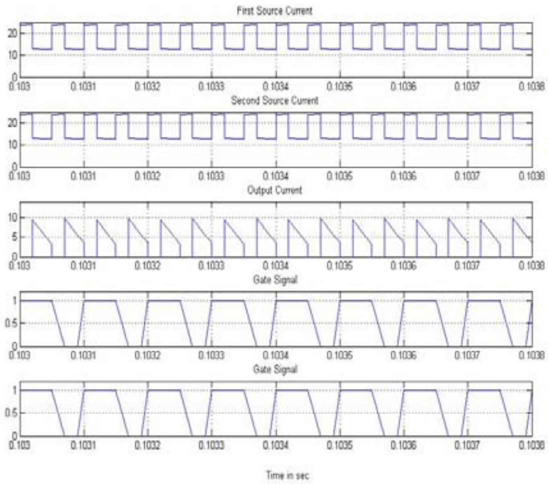

Figure 9: Simulation results of CS converter (case 3)

in a boost phase or free wheeling stage. When only one switch is closed, the converter is said to be in a powering phase as current is delivered to the output rectifier. The same operation occurs in the input stage 2. Figure 9 shows the simulation results.

When both switches of each input stage are ON, high current flows from each source and no power is transferred. But when only one switch is ON current reduced to half for each input stage and power is transferred during this time. If we add the half of the current of each input stage, we would come up with the load current, which means both the source are sharing the load equally. Gate signal for M1 and M3 are also presented in figure 9.

Case4: Input-stages of the converter are running at different duty cycle:

In this case, the switches associated with first input stage are

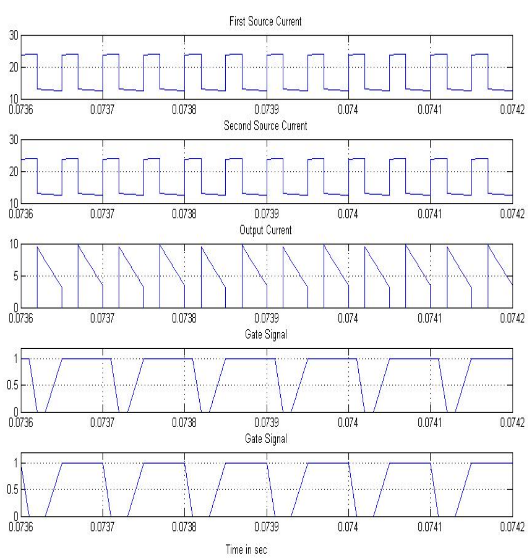

Figure 10: Simulation results of MI CS converter (case4)

operating at 70 % duty cycle whereas the switches in the second-input stage are operating at 60% duty cycle. When the first input stage is in the power transferring stage and the second input-stage is in free wheeling stage, the induced voltage on each winding will be clamped to the output voltage. So there is power transfer in between the two input stages. The simulation results for this case are presented in figure 10.

In this case power is supplied by the input-stage that is operating at higher power level.

VII. Problem Identification

Half-bridge multi-port dc/dc converter could be a good option for accommodating four energy sources. But this topology has disadvantage of having feedback from other sources. If all sources are operating at same duty cycle, this converter can be applied in hybrid power system. But in practical all the input-stages of the converter will not operate at a same duty cycle. From simulation and also with practical implementation, it is observed the feedback exist in different input-stage. Using series diode with MOSFET cannot mitigate the problem of feedback; it blocks the freewheeling path of the inductor. Dual of the half bridge converter is also studied and simulated for this application. But this topology required large inductor. Power transfer stage is less than 50% of the total cycle. Energy stored in inductor is not properly discharged and require snubber circuits and this topology does not transfer the energy efficiently. In order to remove energy stored in inductor we need to have some energy recovery circuit which makes this topology very complicated [7].

The simple way to overcome these problems is to use individual boost or buck-boost converter with each source. This is parallel operation of the converters.

VIII. Parallel Operation of DC-DC Converters

As indicated in section II single input dc-dc converter may be used in a parallel arrangement to connect sources at different voltage levels to a common dc bus. In the hybrid power system under consideration, the micro-hydro and photovoltaic in system produce nominal output voltage of 48V. However this voltage may vary from 44V to 55V. The wind energy conversion system produces a nominal voltage of 24 V. In order to connect the different level of voltage to a common dc bus with a constant voltage of 48V, buck-boost and boost converters are required. Figure 11 shows a block diagram representing the hybrid power system containing multiple dc-dc converters.

If we look at the basic block diagram of the total system, we can see the total system can be subdivided in to five main blocks; i.e.

- Input Sources
- Load Side
- Power electronics interface circuitry
- Controller and
- Sensors

Input sources: The input sources consist of renewable energy sources. For our system the input sources are wind turbine, photovoltaic and micro hydro. Though in our system two wind turbines are considered but for simplicity only one block of wind turbine is shown in the figure 11. The input sources are connected to load through power electronics circuit.

Load side: The load side represent consumer load. But it also include dump load and battery bank. The dump load is nothing but pure resistive load. In some applications it is heating load. The dump load is connected to dc busbar through a solid state relay. The relay is controlled by the supervisory controller. If

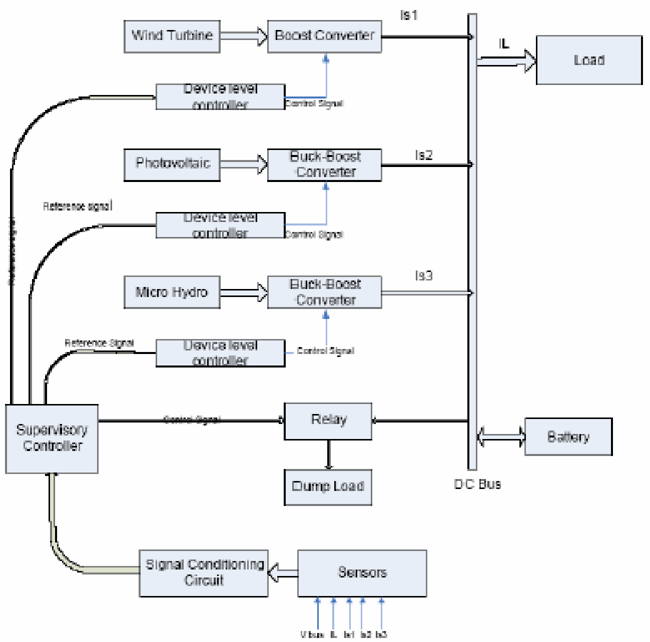

Figure 11: Basic block diagram of the hybrid power system

the generation is more than customer demand, supervisory controller generate control signal to relay to connect the dump load to the system. Battery is considered here as load side component, though it supply power for short duration but it also consumes power for charging. The battery bank voltage maintain the constant voltage of the DC busbar and also it is a control variable. Depending on this voltage, supervisory controller decides whether the battery needs charging or not. If the voltage is below a threshold voltage, it means batteries need to be charged and supervisory controller generate signal accordingly.

Power electronic interface circuitry: Power electronics interfacing circuitries are like bridges between input stages to the output stage. There should be isolation from source side to load side, power electronics devices established this isolation. If the sources are directly connected to load due to variation in source voltage, load side voltage will vary and also different voltage rating sources cannot connect directly to load. As previously mentioned two different voltage rating sources are connected to common DC bus through power converters. As described in the figure wind turbines are connected to DC bus through boost converters where as micro-hydro and photovoltaic are connected to DC bus bar voltage through buck-boost converter.

Controller: the controllers in the system can be further subdivided in to supervisory controller and device level controller. The supervisory controller supervises overall system performance and generates signal according. It also generates reference signal for device level controller. These reference signals are associated with maximum power point tracking algorithm with the device level controller. The supervisory controller takes decision whether which system should put on or should turn off. It produce signal for dump load relay. The device level controllers are solely responsible for generating duty ratios for converters. Here the supervisory controller and device level controllers are micro controller based which is very easy to operate and suitable for stand-alone application.

Sensors: In order to operate successfully, the controller needs to sense some signals. Depending on the control algorithm, number of input signal are measured and conditioned. In the system all the source input current, load current and load side voltage are control variable. They are sensed by proper transducers. As output of the current transducers are not pure dc, so low pass filter is used to block the high frequency ripples. Also the current sensor output is very low in magnitude so amplifier stage is used to amplify the signal.

IX. CONTROL ALGORITHM FOR THE HYBRID POWER SYSTEM

The main challenge is the control of the hybrid energy system. So far no literature has been found about supervisory and modular controller approach to real time system. Few literatures are available on supervisory controller but they are basically on simulation level. Practical implementation of control algorithm for more than one source is available but most of that work on current sharing method or individual level control. One report [8] is available from Riso research institute, where they worked on simulation studies of supervisory and modular controller. Though supervisory controller meet the generation and load demand and modular controller control the power flow from each source. The source or loads are assigned with priority number where they could be easily interchangeable and different source are given different priority number to generate power. As mentioned in [8] they developed program in Matlab and did only simulation of different cases. Also in there system they were are talking about a system comprised of diesel only, wind-diesel or wind only. So this will be first work on hybrid supervisory controller for stand alone wind-photovoltaic and micro hydro system. Also most of the control systems are PC based, so it requires external ac power to run the PC itself. Micro controller based controller overcome this problem for stand alone system where the necessary small power can be supplied from a battery.

The control structure can be sub-divided into two distinct levels:

1. System level control
2. Device level control

The system-level controller or supervisory controller manages the power flows to the controllable elements of the system to help, as far as possible, balance supply and demand. In this level all the inputs are sensed through sensors and generated signals for device level controller. The device level controller works on each power-electronics interface. This control action does not need to be particularly fast but is required to ensure that each individual device functions correctly, producing the correct current, voltage and waveform.

X. System Level Control

The challenge for a supervisory control system is to control the power flows to maintain the DC voltage on the bus bar within the operational limits of the power-electronic converters.

The supervisory controller for hybrid energy system is a plant-wide control system that synchronizes and supervises system operation while distributing the operation control with local controllers and regulators. The distributed control is realized by allowing the system components use their own regulators and control systems to safeguard operation. For instance, a wind turbine has a pitch controller to control its active power and a voltage regulator to control the voltage.

The supervisory controller is responsible for selecting the best mode of operation for the system taking into account the application-specific operating goals, the system design and constraints. The supervisory controller determines set points for different components at different modes of operation and sends them to their individual local controllers.

The controller is separated into two parts: *hardware* and *software*. The *hardware* is characterized by the type of microcontroller and its features. The interfaces with the plant to be controlled (*process interface*) and the operators (*man-machine interface*) are important parts of the hardware and influence the *application programs* (*software*) related to the I/O operations of each interface. The *software* is *application programs*, which are the algorithms of the control system.

In our system controllable components are two wind turbines, one photovoltaic module, one micro hydro, one battery bank and one dump load. Micro hydro is used as base generation and no device level control is applicable to this source. If it has sufficient flow to produce power, it will keep producing power and no maximum point tracker is used in this stage.

For wind and photovoltaic module maximum power point tracker is used and they are discussed under device level controller.

If generation exceeds the demand, the excess power has to utilize or generation needs to cut down. In the system, any excess variation in generation is dumped through dump load. The dump load is nothing but pure resistive load. This load is controlled by relay signal from supervisory controller.

The battery bank in the system keep the DC bus voltage in a constant value, in our system it is 48V. A drop in busbar voltage below a certain threshold limit means that the battery banks need to be charged.

If we consider only generation and demand there may exist only three condition-Generation equal to demand, generation greater than demand or generation less than demand. Depending on these three conditions our supervisory controller worked in three modes. The following section described these three modes in detail.

Mode 1: Load is equal to generation: It corresponds to period of sufficient wind or solar or both to satisfy the total demand. As micro hydro is used as base generation, so the wind and solar energy sources have to track the total demand while the battery bank is inactive. If this is the starting condition, device level controller will search more maximum power point tracking. And if the generation increased the increased power will charge the battery depending on the charge level.

Mode 2: Generation is more than load. The supervisory controller stops the renewable energy sources for maximum generation. In this mode, the battery bank is not requested to supply power to load. On the contrary, under this mode, the battery bank demands the maintenance current or recharge current and becomes part of total demand. The dump load is turned on in this mode.

Mode 3: Generation is less than demand. This mode occurs when generation falls below demand. In this mode battery bank is requested to supply power to the load and charge of the battery is monitored constantly. If it falls below a certain safety limit the supervisory controller has to cut off some load and the dump load is always turned off in this mode..

The basic flow chart of the supervisory controller is given below-

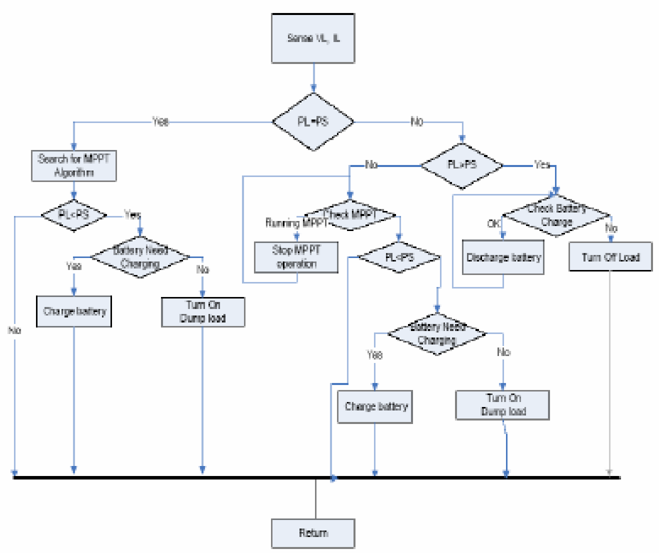

Figure 12: Supervisory controller flow chart

The sensors will sense the voltage and currents of each stage and will help to determine the generation and demand at regular intervals. If the load is equal to generation, the controller for each source will search for MPPT algorithm. If already all the renewable energy sources are at maximum power point, no extra energy can be generated from the sources. On the other hand if the sources are not operating at MPPT, the sources will run at MPPT and the extra energy will be used to charge the battery bank. If the load and generation are not equal, there may be two situations; either load is greater than generation or the load is less than generation. If the load demand is higher than the generation, the batteries need to discharge power to meet the load demand. The battery charge must be monitored at regular intervals, if the battery charge falls below a certain limit, some load will have to be turned off. If generation is more than demand, the extra power will charge the battery bank. A fully charged battery, however, will require that the extra energy be diverted to the dump load.

XI. Device Level Control

The voltage of the main bus bar to which the various DC devices are connected has been selected as 48V DC. Wind turbines output voltages are 24 volts whereas PV arrays and micro hydro output voltage is 48V. However, due to variations in the output voltage of the sources DC-DC converters are required for all the sources. The solar PV arrays and micro hydro sources require buck boost converters, whereas the wind turbine sources require boost converters. These converters are controlled by device level controllers.
The device level controllers for the solar and the wind are discussed in separate section.

XII. Photovoltaic Source

Characteristic of the Photovoltaic Array

All the photovoltaic modules considered in the paper are crystalline silicon- which was used in 94% of all 1200 MW of produced solar cell modules in 2004 [9]. Such modules have current/voltage (IV) characteristics as shown in Figure 13 [10]. The current is mainly affected by changes in solar irradiance (W/m^2) and, to a lesser extent, by other variables such as temperature. But open circuit voltage is mainly affected by temperature and it has negative effect. It means with increase in temperature, open circuit voltage of the pv modules decrease.

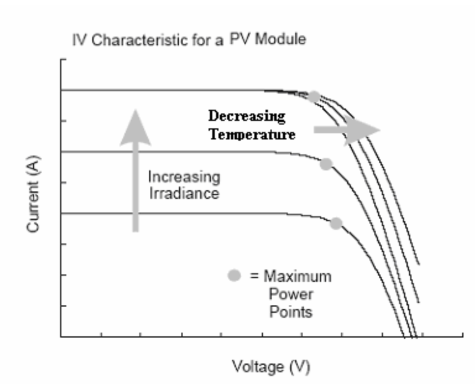

Figure 13: Typical IV characteristic of a crystalline solar PV module

Modules are built from a number of cells in order to supply higher voltage and current. Modules are then connected into an array, with series and parallel connections used to give increases in voltage and current. If the panels are wired in higher voltage series strings, they will have a lower current for the same power level and hence lower resistive losses and thinner, less expensive, wires.

Maximum Power Point Tracking (MPPT)

Various methods of maximum power point tracking have been considered in photovoltaic applications. They can be mainly categorized into three broad groups [10].

- Look Up assignment table method
- Computational method
- Perturbation and observation method

In this research the perturbation and observation method is

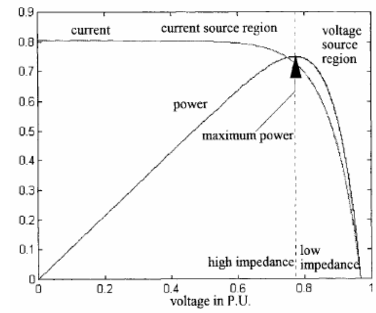

Figure 14: Solar array characteristic curve [11]

proposed in a software program with a self tuning function. The program automatically adjusts the array reference voltage and voltage step size. The problem- incapable of tracking maximum power in fast changing environment, with the method is wished to overcome by increasing sampling frequency.
Solar array characteristic curve under a given insolation is given in figure 14. The internal impedance is low on the right side of the curve and high on the left side and maximum power point is located at the knee of the curve. According to maximum power transfer theory, the power delivered to the load is maximized when the load impedance is equal to the source internal impedance. So if the system is required to operate near maximum power zone, the impedance seen from the converter side needs to be match with the internal impedance of solar array.

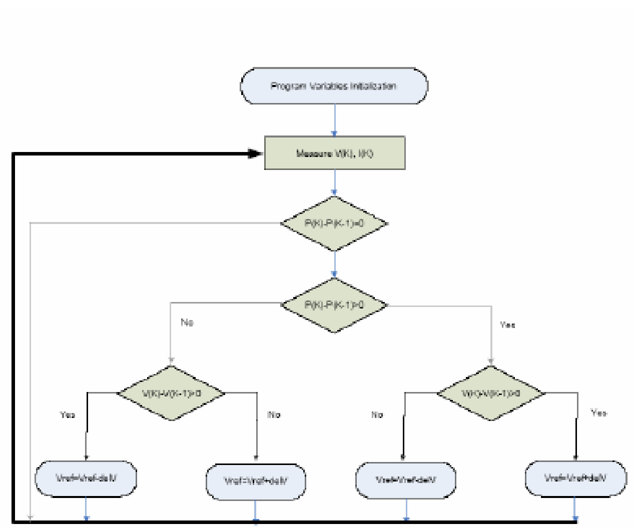

Figure 15: Flowchart of the MPPT control

As the traditional dc/dc converter has negative impedance characteristic, the solar array is required to operate on the right side of the curve to perform the tracking process. The control flowchart in figure 15 illustrates the details of decision processes. If the given perturbation leads to an increase in array power, the next perturbation is made in the same direction. In this way the maximum power tracker seeks the maximum power point continuously.

XIII. WIND ENERGY CONVERSION SYSTEM

Characteristic of the Wind Generator

A wind turbine extracts energy from moving air by slowing the wind down, and transferring this harvested energy into a spinning shaft, which usually turns a generator to produce electricity. The power in the wind that is available for harvest depends on both the wind speed and the area that is swept by the turbine blades [12-14]. It can be formulated by the following equation:

$$P_t = \frac{1}{2}\rho\pi R^2 V^3 \tag{1}$$

Where, P_t =Output power in watts; ρ =Air density in kg/m^3; R=Radius of the swept area of wind turbine in m; V=wind speed in m/s.

The first concept that this formula shows is that when the wind speed doubles, the power available increases by a factor of eight. The only way to increase the available power for low or constant wind speeds is by sweeping a larger area with the blades.

In 1919 Betz calculated that there is a limit to how much power a turbine blade can extract from the wind. He determined that 59.2% of absolute maximum energy can be extracted from the available power [14]. Beyond the Betz Limit of 59.26% energy extraction, more and more air tends to go around the turbine rather than through it, with air pooling up in front. There are additional losses after the Betz limit; small wind turbine blades are never fully efficient, even when running at desired speed; no generator is 100% efficient in converting the energy in a rotating shaft into electricity; there are friction losses from bearings, and from any gearing that is involved in the power conversion. And there are magnetic drag and electrical resistance losses in the alternator or generator. Taking these factors into consideration the output of a wind turbine can be expressed as [15]

$$P_t = \frac{1}{2} C_p(\lambda)\rho A V^3 \tag{2}$$

Where, P_t =Output power in watts; C_p =Power co-efficient (non-dimensional); λ =Tip speed ratio (non-dimensional); ρ =Air density in Kg/m^3; A=Frontal area of wind turbine in m^2; V=wind speed in m/s.

And the term λ is the tip-speed ratio, defined as

$$\lambda = \frac{\Omega R}{V} \tag{3}$$

Here Ω is the rotational speed (in rad/sec) of the wind generator's rotor.

Maximum Power Point Tracking

The wind generator power curves for various wind speeds are shown in figure 16. It is observed that for each wind speed there exists a specific point in the wind generator output power versus rotating-speed characteristic where the output power is maximized. The control of the wind generator load results in a variable-speed operation, such that maximum power is extracted continuously from the wind.

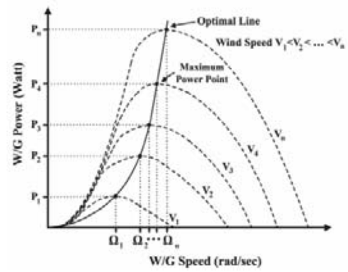

Figure 16: Power curves at various wind speeds

A commonly used wind generator control system [16] is based on the optimal power versus the rotating-speed characteristic, which is usually stored in a microcontroller memory. The wind generator rotating speed is measured; then, the optimal output power is calculated and compared to the actual output power. The resulting error is used to control a power interface.

A control system based on wind-speed measurements has also been proposed in literature [17]. The wind speed is measured, and the required rotor speed for maximum power generation is computed. The rotor speed is also measured and compared to the calculated optimal rotor speed, while the resulting error is used to control a power converter.

In permanent-magnet (PM) wind energy conversion systems, the output current and voltage are proportional to the electromagnetic torque and rotor speed, respectively. In [1],

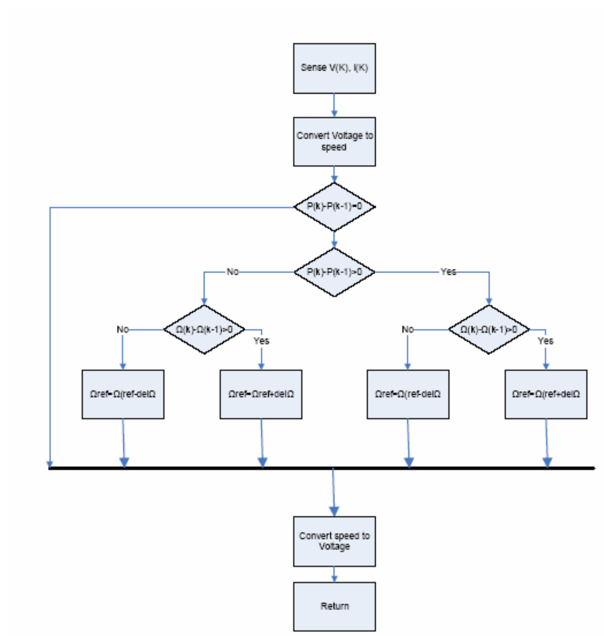

Figure 17: Basic flow chart of the MPPT control for Wind energy conversion system

the rotor speed is calculated according to the measured output voltage, while the optimal output current is calculated using an approximation of the current versus the rotational-speed optimal characteristic. The error resulting from the comparison of the calculated and the actual current is used to control a dc/dc converter.

In this research, the MPPT process is based on monitoring wind generator output power using measurement of output voltage and current and directly adjusting the dc/dc converter duty cycle according to successive output power values. Thus this method neither need to measure wind generator rotational speed or wind speed. But to measure the reference point it applies the concept of reference [18].

The flow chart in figure 17 describes the detail of decision process. Proposed modular controllers and supervisory controller are still under development at the energy system lab, Memorial University of Newfoundland. System performance and experimental test results will be presented in future publications.

XIV. CONCLUSIONS

This paper proposed a multi-input dc-dc converter topology for hybrid energy system and investigates its operation through simulation. The simulation studies show that the topology is not suitable for multi source hybrid energy system. So the alternate solution –parallel operation of the converter is described in this paper. This paper also investigates control strategies and proposed supervisory and modular controller approach for a hybrid power system. The basic flow charts for supervisory and the device level controllers are also presented in this paper.

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