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Load Management System with Integration of Renewable Energy Resources

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Abstract: This article presents, a load management system is designed and implemented to integrate renewable energy resources (RES) (solar and wind), which manage the load according to the supply/demand and the user's priorities. The system is implemented on a hybrid system integrating wind energy, solar energy, utility supply, and battery energy storage system. Load management is carried out via switching of the loads. The sources can also be turned ON and OFF. During excess power, the battery module works as an energy storage unit or backup energy supply unit during demand. Loads can be turned ON and OFF wirelessly via GSM. The grid operator can switch the loads by simply sending a command via a short service message (SMS). In the end, the system is tested, and the results are presented. The hybrid system is simulated in MATLAB/Simulink first and then hardware implementation is carried out, which involves integrating renewable resources via converters and load management by switching using a microcontroller (Arduino).

Keywords: Battery, hybrid system, load management system, renewable energy sources (RES), solar energy, wind energy

1. Introduction

With the swift increase in demand for electricity, the advancement of hybrid energy resources has played a significant part in power generation in recent years. The systems designed for the generation of energy from natural resources lack the proper management of the energy produced. There is no effective utilization of the resources, and there is also an issue of load shedding and energy crisis due to ineffective load management. The effectiveness of the power generating system can be improved by enhancing the hybrid system. One approach is to improve it through the use of renewable energy sources (RES) to lessen the cost of convenient energy [1], [2], [3], [4]. RES has great economical potential. The proportion of renewable energy was 25 % in 2015 in the power sector which would increase to 85% in 2050 in the world [5]. For RES use, it is a favorable situation. For an efficient supply of energy, not just conventional, but also renewable energy technologies need to be used efficiently. A rational blend of conventional and renewable energy resources should therefore be established within the energy supply system [6].

Under-developing countries such as Pakistan, there has been a shortfall in electric power since 2006. At present, with the need for electricity surpassing the supply and recurrent power outages, the country is facing the worst electricity shortage in its history. An effort has been made to have a power supply 24 hours in [7], [8], [9]. Nowadays, the production

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capacity is enough to meet the power needs, but the transmission system cannot handle the increasing demands of the load and there is electricity theft as well [10]. The efficiency of most power units and transmission lines and their efficiencies are greatly reduced as a result of being outdated. Compensating for energy scarcity and reducing emissions issues will be resolved by the large-scale use of RES for the production of electricity. A single feeder feeds the whole specific area (secondary power distribution) which disables the management of the load according to the pre-set priorities such as hospitals to be the highest preference, then comes industrial loads, commercial and residential loads [11]. Renewable energy resources enable the consumers to have an uninterrupted power supply without depending upon the transmission or distribution system. Approximately 60% of electricity is generated from fossil fuels that are not best very high priced however also emit ample poisonous carbon dioxide and other contaminants into the environment [12]. While, in this case, a grid-integrated system is widely practiced throughout the world, and due to the voltage imbalance of the system, its implementation discourages in Pakistan.

Given the potentially substantial amount of generation from alternating power sources, MGs (micro-grids) have a small impact on the power grid. Although RES has many benefits, they are uncertain, incredibly intermittent, and climate-sensitive, requiring RES to combine energy sources [13], [14], [15]. Hybrid green energy sources are very operative in generating power, even though when there is the nonappearance of a single source of power [16]. Several studies have been conducted to optimize and aim RES share in MGs with or without the use of a traditional generation system [17], [18]. To provide continuous energy, designed a hydro-solar-based power generation system. Load sharing has been discussed in [19]. In [20], with the aim of countryside electrification, the author researched and presented wind//PV/diesel/battery mixture system. Likewise, with the practice of battery storage systems and a super capacitor (SC), the authors proposed wind-based and PV power and the management of energy for the standalone grid system [21], [22]. For grid-independent applications, the author identified a PV/wind/SC/battery in [23]. In [24], There's been discussion of a coordinated control scheme focused on PV/SC/battery and power management for small-scale MG. A hybrid system is a long-term system for power employment and power can be continuously generated at any season [25].

Examination of the growing problem of power demand reveals that green energy technologies are well-positioned to play a major role in the potential evolution of the supply of energy resources [26]. In this proposed system, a hybrid system focused on a wind/PV/battery/utility supply is designed and developed to cope with the mentioned problems. Hybrid systems provide the opportunity for significant environmental advantages and facilitate the public by high-efficiency RES incorporation.

The proposed system integrates solar, wind, and utility supply with battery storage. Sources are converted to DC which makes a DC bus. An inverter converts this DC into AC, and this AC is supplied to the load section. The battery is also there for the power supply in case if the power does not meet the requirements from the other sources. With Load 3 being the lowest priority and Load 1 being the highest priority, there are three load sections. Each load is controlled by a microcontroller unit which can turn on and off the load according to the situation. The connectivity of the user is achieved by GSM and its module is connected to the microcontroller unit which enables it to receive the commands of switching of load and source by the user wirelessly. The microcontroller switches the individual loads according to the commands of the user.

2. Proposed System and Algorithm

Fig. 1. Presents the proposed hybrid system. The system comprises four modules i.e., wind turbine, PV module, utility supply, and battery storage, which are connected to the 200V DC bus. The inverter converts the voltage at the DC bus to AC and then supplied it to the loads via the feeder. Three loads are connected with Load 1 having the highest priority and load 3 having the least priority.

Fig. 2 shows the proposed algorithm for load management. The system first measures the power requirement of the load and the available power from the Photovoltaic (PV) module. The difference between the available power from PV and the required power is calculated. If the available power is less than the needed power, the system checks the available power from the wind turbine. If the available power is more than the needed power, the system checks if the battery's SOC (state of charge) is less than 80%, it charges the battery. The system checks if both wind and solar systems are providing enough required power, the systems repeat this cycle, and if the power from wind and PV is not enough, it gets power from the battery, and battery discharging starts. If still there is a shortage of power, the system checks for the utility supply and gets power from there. If the utility supply is not available, then the low-priority loads are cut off either by the system. If in any scenario, there is a need to manually turn off the loads, the user can turn ON and OFF the loads via GSM wirelessly. Fig. 3 shows the system structure. The microcontroller controls the switching of the loads and sources according to the algorithm. The power available from the sources is displayed on the Liquid Crystal Display (LCD). The loads can be turned ON and OFF via GSM. When the user sends a command via GSM, the microcontroller switches the load which allows the user to switch the loads remotely.

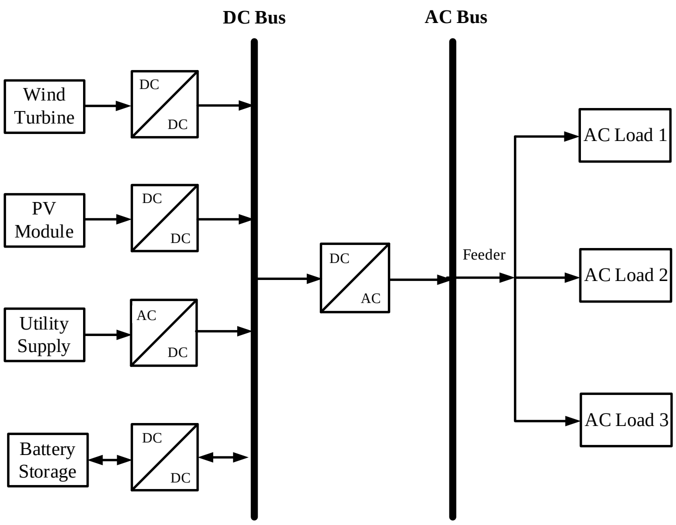

Fig. 1 – structure of proposed hybrid system

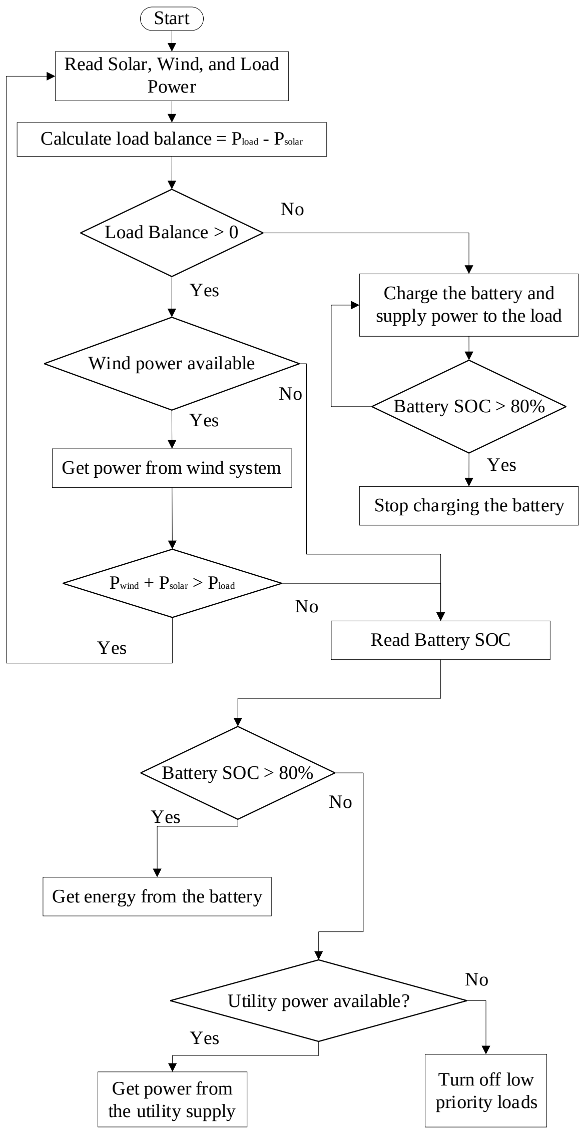

Fig. 2 - Proposed algorithm for load management

3. Modeling of the Subsystems

3.1 Solar System

A PV module is connected to an MPPT (maximum power point tracking) boost converter which tracks the maximum power from the module. The incremental conductance algorithm is used for maximum power point tracking. The output from the MPPT boost converter is then connected to the DC bus. Fig 9 in section 4 shows the maximum power tracked by the MPPT.

3.2 Wind Section

A permanent magnet direct current (PMDC) generator is used for wind power generation. The buck-boost converter with closed-loop control is used to convert the voltage to the DC bus voltage level. PI (proportional-integral) control is used in the control loop of the buck-boost converter. The DC bus is then fed by the buck boost converter. Fig. 5 shows wind speed variation and converter output voltage.

3.3 Utility Supply Section

The voltage level of the utility power supply is transformed to a voltage level which is then fed to a full bridge diode rectifier which converts the voltage from AC to DC. The filter is used to reduce the ripples and then this supply is fed to the DC bus.

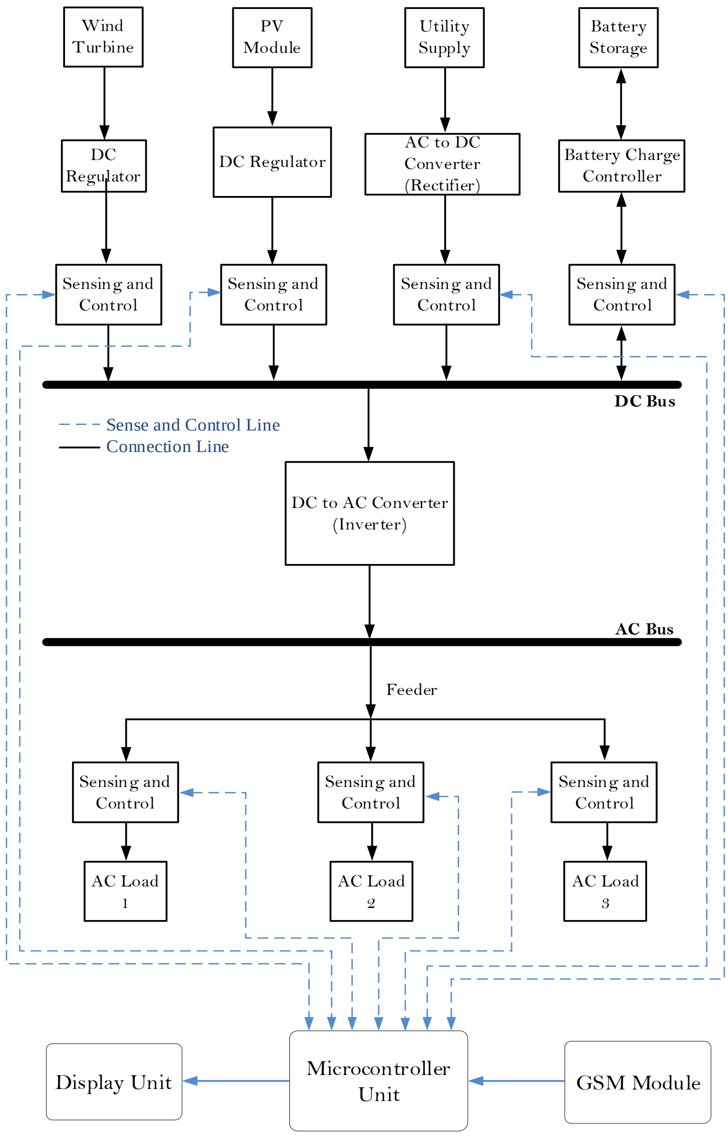

Fig. 3 - The complete model of the system

3.4 Battery Storage Section

A bidirectional DC-DC converter is used for the control of charging and discharging of the battery. The bidirectional converter is a closed-loop buck-boost converter with PI control. The battery used is a 30 Ah lead-acid battery. The charging current of the battery is chosen to be 10% of the per hour rated current i.e., 3 Amperes.

3.5 Inverter section

The supply from the DC bus is fed to an inverter which converts the DC voltage to AC and provides these at the AC bus. Sinusoidal Pulse Width Modulation (SPWM) inverter is used to get the output voltage closed to a sinusoidal voltage. The frequency of the output voltage is 50 Hz. The supply from this section is then fed to the load section via a feeder.

3.6 Load Section

The load section consists of three AC loads with load 1 having the highest and load 3 having the least priority. There are switches connected at each load to control the switching of the load. The loads can be turned on and off via GSM. When the user sends a command via GSM, the microcontroller switches the load which allows the user to switch the loads remotely.

3.7 GSM

A GSM is employed to control the switching of the loads and sources wirelessly. The GSM module is connected to the microcontroller which gets the command from the user via SMS in the form of alphabets.

3.8 Microcontroller

Arduino microcontroller is used in the implementation of the system. The microcontroller controls the loads and sources via relays according to the algorithm or the user's commands.

3.9 LCD

The LCD module is connected to the microcontroller to display the various parameters such as which source is being currently used, the power available from the sources, and the power being utilized currently.

4. Simulation Results

The hybrid system is simulated in Simulink/MATLAB. Fig. 4 displays the Simulink/MATLAB model of the system. Different sections are highlighted in a different color.

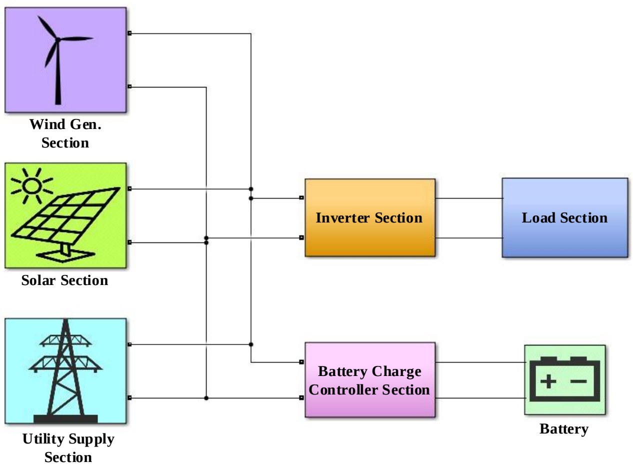

Fig. 4 - Simulink/ MATLAB model of the hybrid system

Fig. 5 shows the variation of generator output voltage with the variation of wind. The output voltage of the generator varies according to the wind speed. The voltage also follows the same trend as that of the wind. The output voltage of the buck-boost converter in wind is also shown in fig. 5. The output voltage of the dc-dc converter is equal to the reference voltage i.e., 200 V. The converter successfully tracks the reference voltage of 200 V. Fig. 6 shows the voltage across the load. These are the output voltage of the inverter. There is a transient period at the start and then voltage gets settled to a steady state. The frequency of the output AC voltage is 50 Hz. Fig. 7 shows the close-up view of the AC load voltage.

Fig. 8 shows the output voltage of the MPPT boost converter. The voltage is converted to the reference value of 200 V and the converter follows the reference value after the transient period. The maximum power tracked by the MPPT is shown in fig. 9. The MPPT converter is tracking for maximum power. It checks continuously the voltage where power is maximum and then chooses that voltage where maximum power is available. Fig. 10 shows the THD (total harmonic distortion) of the inverter's output voltage to be 52.47% for a modulation index of 1. This result of THD of the SPWM converter is also verified from the literature. Fig. 11 shows the voltage after rectification from the utility supply. The ripples in the DC are reduced due to the filter. The same DC voltage is converted to AC and is shown in the second part of the figure. Fig. 11 shows the charging of the battery. The battery is being charged at 3 A current and the SOC of the battery is increasing as shown in the display block. Fig. 12 shows the discharging of the battery where the discharging current of the battery is according to the demand of the system and the SOC of the battery is decreasing in this case.

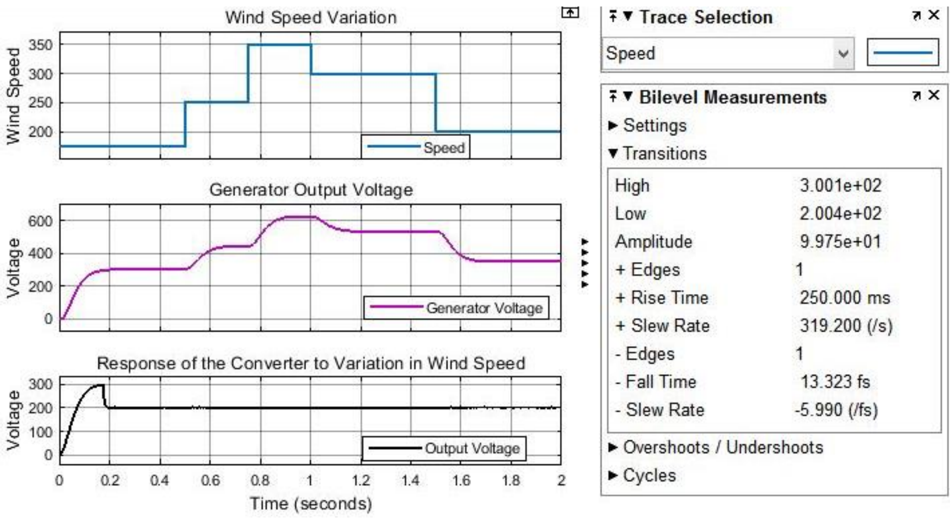

Fig. 5 - Wind speed variation and converter output voltage

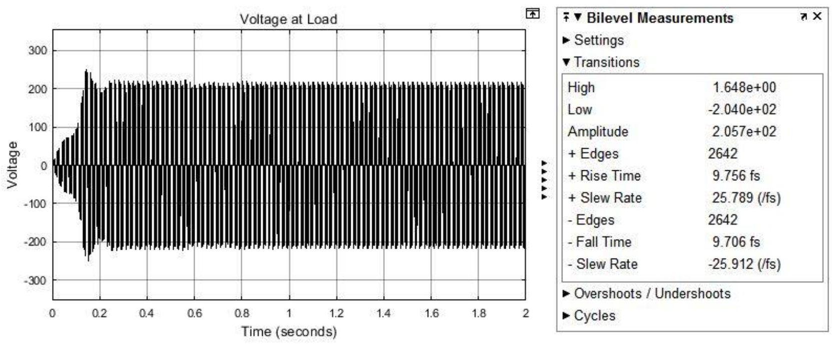

Fig. 6 - Voltage across the load

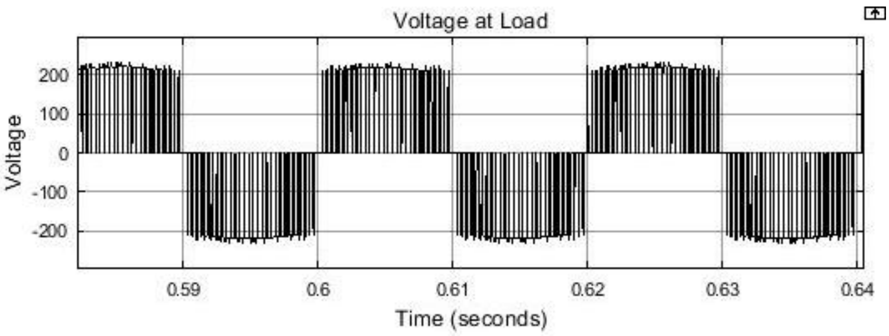

Fig. 7 - Output voltage from the SPWM inverter (close-up view)

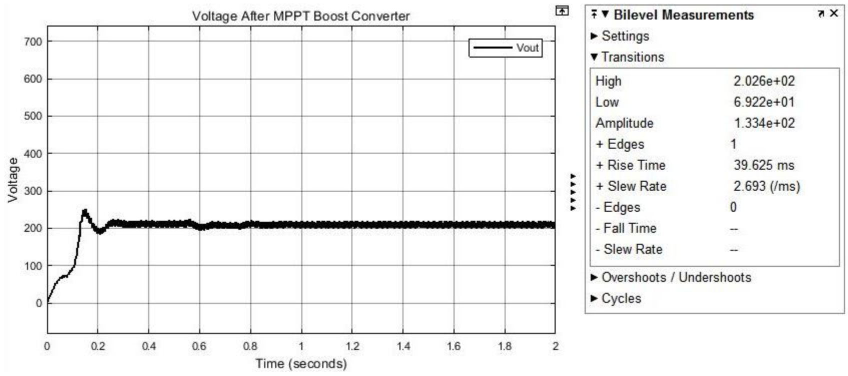

Fig. 8 - Voltage after MPPT boost converter

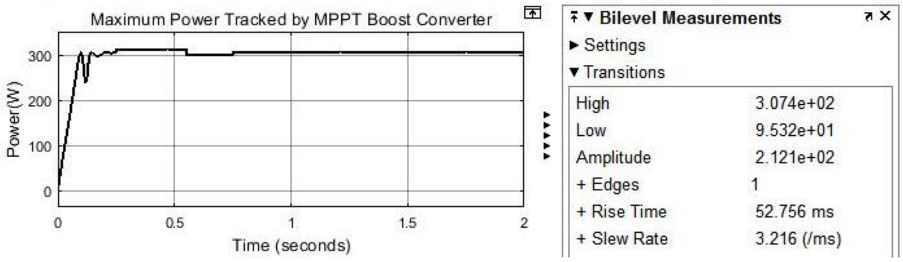

Fig. 9 - Maximum power tracked by MPPT boost converter

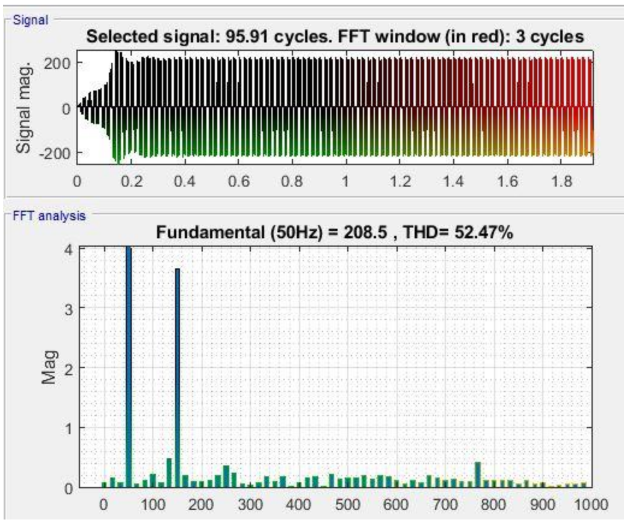

Fig. 10 - THD of the output voltage from the SPWM inverter

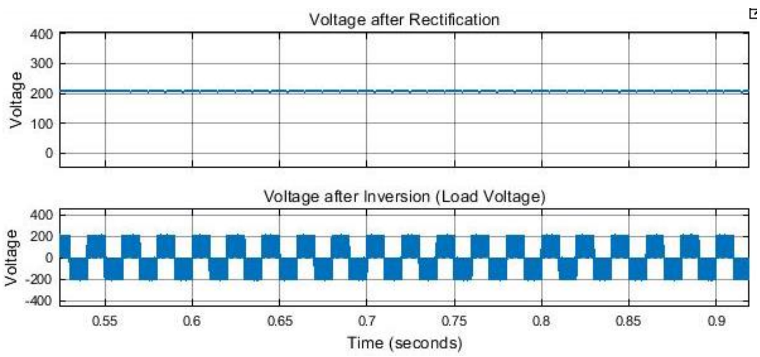

Fig. 11 - Voltage after rectification of WAPDA supply, and load voltage

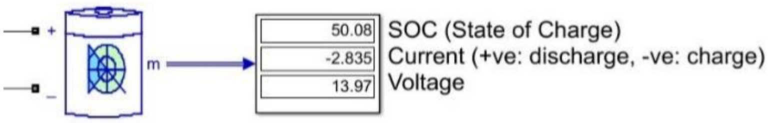

Fig. 12 - Battery in its charging state

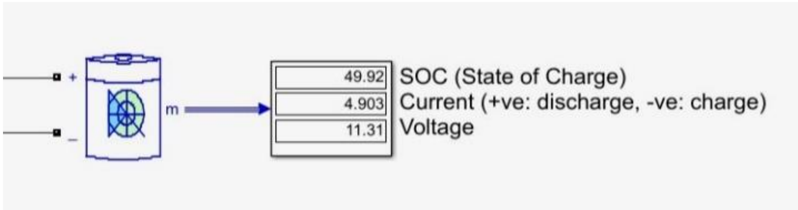

Fig. 13 - Battery in its discharging state

5. Hardware Results

Fig. 14 shows the complete implementation of the system. The sub-parts of the system are highlighted and labeled. The system gets the power from three sources i.e., utility supply (WAPDA), wind, and solar. The rectifier is connected to the utility supply which converts the voltage from AC to DC after the transformer steps it down. A buck/boost converter is connected after the wind and solar to keep the voltage to the desired level (12 V). A voltage divider circuit is used to measure the available voltage from the three sources and the battery. The voltage divider circuit provides the readings of the sources to the microcontroller which are then displayed. An inverter with push-pull topology is used to convert the DC (12 V) voltage to the AC voltage. The rating of the inverter is 300 VA. The inverter is being controlled by a pulse generator (gate drives). A transformer (center-tapped) converts the 12 V AC into 220 V AC. The rating of the transformer is the same as that of the system i.e., 300 VA. This supply is then fed to the three loads. The supply to the loads is measured by the CT and PT and the data is fed to the microcontroller.

The loads are controlled by the microcontroller via relays. Figs. 15 (a) & (b) represents the wind and solar setup. A display unit is connected to the microcontroller which shows the necessary data such as sources in use solar (S=17.95), wind (W=6.07) battery (B=7.92) & utility supply (M=12.40), load voltage (OUT V=113.23), current (A=0.08), and power are shown in Fig. 15 (c). A GSM module is connected to the microcontroller which, on the command of the user, controls the switching of the load. The user can turn the loads ON and OFF wirelessly by sending an SMS using a mobile phone. An indicator indicates in case of low battery voltage and low available power supply, after which the user can turn OFF the low priority loads. Table 1 shows wind voltage variation w.r.t. speed.

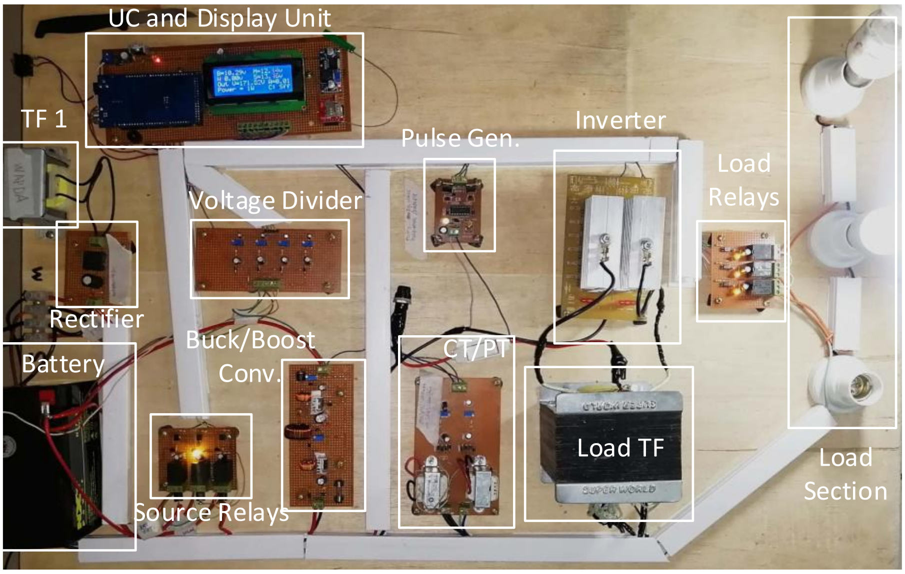

Fig. 14 - Hardware setup of the complete system

Table 1 - Wind voltage variation w.r.t. speed

RPM	Voltage
48	1.82 V
95	3.52 V
196	7.16 V
224	8.85 V

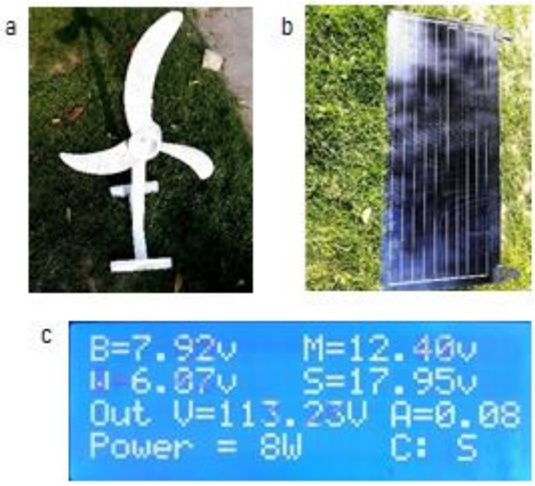

Fig. 15 - (a) wind system setup; (b) solar system setup; (c) LCD for voltage and power

6. Conclusion

This paper presents a load management system with the integration of RES. The system is integrating outdated and renewable energy for the efficient supply of energy to the consumers. Since all the renewable energy resources are not necessarily accessible at all times, the integration of traditional energy resources (utility supply) enables us to encounter the demand. A battery storage system is also employed to make the system more reliable. Furthermore, a proper power flow is developed and embedded into a microcontroller for real-time load management practically. A GSM system is employed to control the loads wirelessly. The display system allows the user to monitor the different parameters of the system. The complete system is successfully implemented.

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References

[1] I. E. Agency and F. Birol, *World energy outlook 2013*. International Energy Agency Paris, 2013

[2] S. Aissou, D. Rekioua, N. Mezzai, T. Rekioua, and S. Bacha, ‘Modeling and control of hybrid photovoltaic wind power system with battery storage’, *Energy Convers. Manag.*, vol. 89, pp. 615–625, Jan. 2015, doi: 10.1016/j.enconman.2014.10.034

[3] D. Amorndechaphon, S. Premrudeepreechacharn, and K. Higuchi, ‘Grid-connected CSI for hybrid PV/wind power generation system’, in *SICE Annual Conference 2011*, 2011, pp. 727–732

[4] K. Mehmood, H. T. U. Hassan, A. Raza, A. Altalbe, and H. Farooq, ‘Optimal Power generation in energy-deficient scenarios using bagging ensembles’, *IEEE Access*, vol. 7, pp. 155917–155929, 2019

[5] P. Balamurugan, S. Ashok, and T. L. Jose, ‘Optimal operation of biomass/wind/PV hybrid energy system for rural areas’, *Int. J. Green Energy*, vol. 6, no. 1, pp. 104–116, 2009

[6] A. E. Baltas and A. N. Dervos, ‘Special framework for the spatial planning & the sustainable development of renewable energy sources’, *Renew. Energy*, vol. 48, pp. 358–363, 2012

[7] M. Engin, ‘Sizing and simulation of PV-wind hybrid power system’, *Int. J. Photoenergy*, vol. 2013, 2013.

[8] K. Mehmood, Z. Li, M. F. Tahir, and K. M. Cheema, ‘Fast excitation control strategy for typical magnetically controllable reactor for reactive power compensation’, *Int. J. Electr. Power Energy Syst.*, vol. 129, p. 106757, 2021

[9] K. Mehmood *et al.*, ‘Short term power dispatch using neural network based ensemble classifier’, *J. Energy Storage*, vol. 33, p. 102101, 2021

[10] M. J. Espinosa-Trujillo, M. Flota-Bañuelos, D. Pacheco-Catalán, M. A. Smit, and Y. Verde-Gómez, ‘A novel stand-alone mobile photovoltaic/wind turbine/ultracapacitor/battery bank hybrid power system’, *J. Renew. Sustain. Energy*, vol. 7, no. 2, p. 023125, 2015

[11] K. Mehmood, K. M. Cheema, M. F. Tahir, A. Saleem, and A. H. Milyani, ‘A comprehensive review on magnetically controllable reactor: Modelling, applications and future prospects’, *Energy Rep.*, vol. 7, pp. 2354–2378, 2021

[12] M. Fadaeenejad, M. A. M. Radzi, M. Z. A. AbKadir, and H. Hizam, ‘Assessment of hybrid renewable power sources for rural electrification in Malaysia’, *Renew. Sustain. Energy Rev.*, vol. 30, pp. 299–305, 2014.

[13] S. Farahat, M. Y. Jahromi, and S. M. Barakati, ‘Modeling and sizing optimization of stand-alone hybrid renewable energy systems’, 2012

[14] A. Saleem, N. Liu, J. Hu, A. Iqbal, M. A. Hayyat, and A. Waqar, ‘Equation-Based Design of Self Charged Solar-Powered Electric Vehicle’, in *2020 5th Asia Conference on Power and Electrical Engineering (ACPEE)*, 2020, pp. 1106–1110

[15] D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, and R. Gorini, ‘The role of renewable energy in the global energy transformation’, *Energy Strategy Rev.*, vol. 24, pp. 38–50, 2019

[16] A. Saleem, A. Iqbal, M. A. Hayat, M. K. Panjwani, F. H. Mangi, and R. M. Larik, ‘The effect of environmental changes on the efficiency of the PV system’, *Indones J Electr Eng Comput Sci*, vol. 18, no. 1, pp. 558–564, 2020.

[17] A. Hepbasli, ‘A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future’, *Renew. Sustain. Energy Rev.*, vol. 12, no. 3, pp. 593–661, Apr. 2008, doi: 10.1016/j.rser.2006.10.001.

[18] F. Jamil, ‘On the electricity shortage, price and electricity theft nexus’, *Energy Policy*, vol. 54, pp. 267–272, 2013

[19] F. Rashid, R. Ahmad, H. M. Talha, and A. Khalid, ‘Dynamic Load Sharing at Domestic Level Using the Internet of Things’, *Int. J. Integr. Eng.*, vol. 12, no. 4, pp. 57–65, 2020

[20] L. V. Kulikova, A. S. Evmenchik, and V. N. Delyagin, ‘Optimization Algorithms to Solve Problems of Comprehensive Electrification Based on Renewable Energy Sources’, *Russ. Electr. Eng.*, vol. 89, no. 12, pp. 689–694, 2018

[21] I. Mahendravarman, S. A. Elankurisil, M. Venkateshkumar, A. Ragavendiran, and N. Chin, ‘Artificial intelligent controller-based power quality improvement for microgrid integration of photovoltaic system using new cascade multilevel inverter’, *Soft Comput.*, vol. 24, no. 24, pp. 18909–18926, Dec. 2020, doi: 10.1007/s00500-020-05120-2

[22] J. Margeta and Z. Glasnovic, ‘Feasibility of the green energy production by hybrid solar+ hydro power system in Europe and similar climate areas’, *Renew. Sustain. Energy Rev.*, vol. 14, no. 6, pp. 1580–1590, 2010.

[23] A. N. Menegaki, ‘Growth and renewable energy in Europe: Benchmarking with data envelopment analysis’, *Renew. Energy*, vol. 60, pp. 363–369, 2013

[24] M. M. Rafique and S. Rehman, ‘National energy scenario of Pakistan–Current status, future alternatives, and institutional infrastructure: An overview’, *Renew. Sustain. Energy Rev.*, vol. 69, pp. 156–167, 2017

[25] F. Rashid, W. Nadeem, A. Hafeez, and A. Nawaz, ‘An Effort towards Zero Percent Load Shedding utilizing Four Different Sources’, *Indian J. Sci. Technol.*, vol. 12, p. 28, 2019

[26] Varun and S. K. Singal, ‘Review of augmentation of energy needs using renewable energy sources in India’, *Renew. Sustain. Energy Rev.*, vol. 11, no. 7, pp. 1607–1615, Sep. 2007, doi: 10.1016/j.rser.2005.11.002