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Seamless Control Method for Wind-PV-Battery Operated Water Pumping Model

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Abstract: Water pumping model (WPM) is essential part in modern days for human's daily activities. The WPM powered by renewable energy power sources (REPS) can reduce the pollution as well as a best solution for many other problems. Implementation of a backup power source through REPS for WPM can also help in decreasing the peak load on the utility grid. Proper sizing of a hybrid power supply system (HPSS) can ensure a consistent water supply to consumers. The wind and photovoltaic modules (PVMs) based HPSSs are two major REPS which commonly used in worldwide. Nevertheless, an energy storage mechanism is required to uphold energy equilibrium within the system due to the unpredictable fluctuations in both irradiance and wind speed. Hence, required number of batteries needs to be integrated to the system with the help of proper converter to make continuous water supply without any interrupt. Adequate space is available for the installation of PVMs and wind systems on both apartments and overhead water tanks in various rural and urban locations. Therefore hybrid PVMs-Wind-Battery based WPM is useful on such places. However, to achieve the best effective and efficient operation of the system, proper coordinated energy management coordination should be developed among wind, PVMs, motor, pump and battery bank unit (BBU). Therefore, a centralized novel energy management approach is designed in this paper. A PMDC generator is included in wind system and PMDC motor is coupled with water pump to reduce losses. Maximum power point tracker circuits (MPPTC) are utilized for optimizing the performance of both wind turbines and PVMs. The two MPPTCs have been combined into a shared dc-link. The BBU is connected to the dc-link via a bidirectional circuit. The bidirectional circuit will maintain voltage at dc-link to drive the PMDC motor corresponding to higher efficiency point. OPAL-RT devices have been designed to showcase outcomes across different operational modes through Hardware-in-Loop technology.

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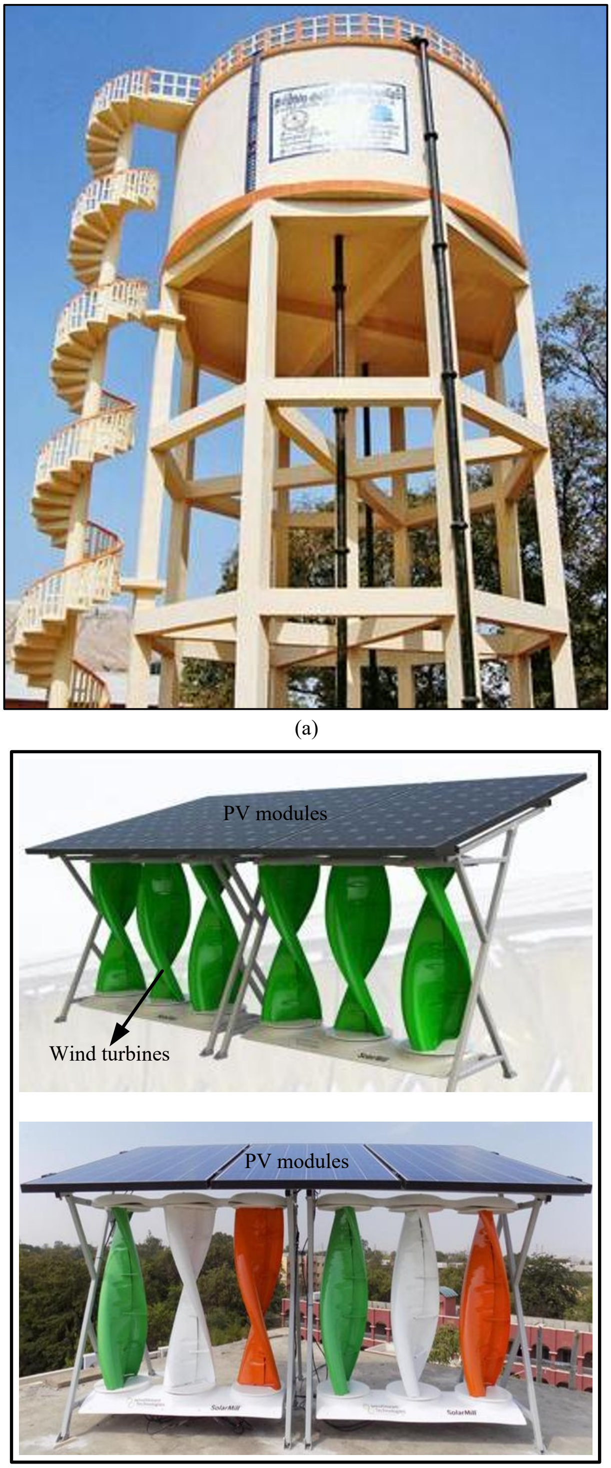
Keywords: Wind, Photovoltaic, Water Pumping System, Wind generation, Energy management system, PMDC.

Nomenclature:
Water pumping model: WPM.
Renewable energy power sources: REPS.
Hybrid power supply system: HPSS.
Photovoltaic modules: PVMs.
Battery bank unit: BBU.
Maximum power point tracker circuits: MPPTC.
Hardware – in the – Loop: HIL.
Permanent magnet direct current: PMDC.
State of charge: SoC.
Energy management system: EMS.

1. Introduction

Water is the most important resource for humans in order to carry out their everyday tasks. A pump is necessary to transport water from underground to the utility point for use. Overhead tanks are often built in numerous regions for the purpose of storing water in order to provide enough supply dependent on demand. Furthermore, separate tank systems are built in flats to meet their daily demands. A pump is needed to move the water from beneath to these water storage devices, which are located at great heights. The pump should be powered by an electric motor. Because of their simplicity and low cost, induction motors are commonly used to power pumps. However, induction motors require a lot of reactive power, which puts a strain on the utility grid, especially during highest load demand [1-3]. As a result, establishing independent WPM powered by hybrid REPS is the greatest option for reducing load demand on the utility grid [1, 4]. Furthermore, a seamless control-based WPM is required to operate it automatically without the need for any people.

Electricity production through PVMs and wind energy based power conversation units are very famous in many places across the world. A wind power system required an electrical generator coupled with a turbine to produce electric power, but PVMs can directly produce electrical power from solar energy by photo electric effect. The reliable power cannot be make by using any single power source from REPS (i.e., either wind or solar). Practically there is a sufficient available place and required height is available on an overhead tanks as well as apartments as shown in Figure 1 for installing both PVMs as well as wind power generation systems. However, energy storage devises like batteries must be integrated into the WPMs along with REPS to make an uninterrupted water supply. Therefore, hybrid Battery-PVMs-wind combination can be able to supply stable as well as reliable electrical supply to motor for driving the pump. The hybrid wind-PVMs system configuration presented in Figure 1(b) is intended to maximize space use while limiting wind turbine size. This configuration can also eliminate the partial shade impact of wind turbines on PVMs. Water is often lifted from subterranean tanks/apartments using 5-10hp motors. A dc type motor is selected to avoid an inverter for making a cost effective setup. A PMDC based generator is chosen in wind generation and motor is considered for driving the pump to minimize loses. Therefore, the proposed configuration is a cost effective as well as consume less loses. A BBU can be selected based on requirement for backup to provide uninterrupted water supply. Hence, a proper designing of the BBU is needed for particular application based on requirement as well as affordable cost.



(b)
Figure 1: (a) Above-ground water tank (b) hybrid wind-PVMs.

The document is offered to achieve the bellow goals:

- To supply continuous water supply, an effective hybrid standalone system is developed.
- To achieve a seamless operation, a master control unit is designed.
- To achieve an effective and efficient EMS operation among all sources, load and BBU by proposed control.
- To examine various responses of the system under different operating conditions by establishing an HIL setup with OPAL-RT units.

The paper is summarized under following sections. The description of the system along with ratings is presented in section-2. The proposed control method is provided in sections-3. The Section-4 is summarized with HIL based results under various operating conditions. The paper concludes with a summary and important references.

2. System Description and Ratings

A Hybrid BBU-Wind-PVMs based standalone power generation system for WPM is presented in Figure 2. Individual MPPTCs are employed for wind and PVMs power generation units to achieve their best utilization. Outputs of all MPPTCs are interconnected parallel to establish a dc-link. A BBU which consists of multiple batteries is connected to dc-link through a bidirectional device. A control method has been devised for bidirectional circuits to ensure the efficient discharging and charging of the BBU. The PMDC type generator in wind system and motor for driving the WPM are considered in this paper to make system less loses. The PMDC motor is directly connected to dc-link through a simple switch since the voltage at dc-link is maintaining at its reference through a dc to dc bidirectional circuit. Therefore, an extra device is not required to the motor for controlling. The extra simple switch can prevent the PMDC motor from frequent OFF and ON. This switch operates automatically by managing a signal created by the tank's water level and the SoC of the BBU. To lift water from subterranean to above tanks, 5-10kW motors are often used. However, the actual rating of a motor is determined on the height of the above tank/apartment as well as the level of the water. A PMDC with a 5kW rating, as shown in Table-1.is considered in this paper to drive the pump. A 4.5kW rating of PVMs [5] and 3.0kW rating of wind power generation system [6, 7] are considered in this paper to run 5.0kW PMDC motor effectively. Respective parameters of PVMs and wind systems are listed in Table-2 and Table-3. The surplus power will be stored into BBU for further usage when there is no sufficient power available to run the PMDC motor. The motor will be running at constant speed since BBU can maintain energy balance in the system by regulating voltage at dc-link at desired value. This can be possible by managing discharging and charging of the BBU through bidirectional circuit. As a result, the reference voltage for dc-link is set to 240V, which is equivalent to the rated voltage of the motor. Controlling the switch 'T' shown in Figure 2 allows the motor to run continuously. Both signals 'A' and 'B' are detected by sensors that correspond to the upper (98.0%) and lower (60.0%) levels of the water tank, respectively.

Similar types of WPMs based on HPSS are preserved by many scholars recently, few of them given in this section. Induction motor driven WPMs powered by PVMs are proposed by authors in [1-3]. However, systems presented in [1-3] require an inverter to run the induction motor which increases the cost of the system. A novel control method for a boost zeta converter is developed on PVMs based WPM in [8]. Authors in [9-11] proposed the WPM powered by PVMs with the help of BLDC motor, but the system has more costlier since used an inverter which is not inexpensive for the installation of above tanks as well as tanks on apartments. To increase system performance under mismatching situations, the authors of [12] presented a WPM using a SEPIC converter. The authors of [13] described a single stage grid-connected PVMs-based WPM powered by a switching reluctance motor, but it is a grid-connected system. The authors of [14] offer a PVMs-powered wireless control system for a WPM. The authors of [15-16] offer a PVMs-based WPM with a storage tank for rural area applications. The authors of [17] developed a PVMs-powered WPM with automated control for irrigation purposes. However, the models described by the authors in [1-3, 8-17] did not contain wind systems. In [18-25], the authors showed WPMs with wind energy for a variety of applications. However, many writers have not considered batteries for energy storage; they require additional circuits to drive their motors and do not have seamless controls. As a result, an efficient EMS is necessary to create a seamless system that is more appropriate for WPM.

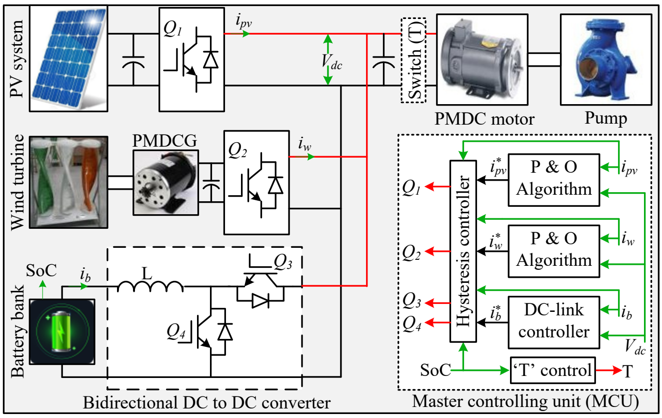


Figure 2: WPM with hybrid REPS and BBU.

Table-1: PMDC Motor Parameters.

S.No	Parameters	Units
1	Rated power(kW).	5.0.
2	voltage(V).	240.
3	Resistance of Armature winding(Ω).	0.5.
4	Inductance of Armature winding(H).	$12x10^{-3}$.
5	Inertia constant(kgm^2).	$4.71\ x10^{-3}$.
6	Viscous Friction coefficient(Nms/rad)	$2\ x10^{-3}$.
7	Torque (Nm/A).	0.5.
8	EMF constant at the back(Vs/rad).	0.5.

Table-2: PV system parameters

S.No	Parameters	Value Units
1	Modules power	300.1W.
2	Voltage at open module.	45.70V.
3	Current when short circuit.	8.55A.
4	Vmpp voltage.	37.50V.
5	Impp current.	7.99A.
6	Array of series modules.	5.0
7	The total number of parallel arrays.	3.0
8	PVMs voltage at Gmax.	187.50V.
9	PVMs current at Gmax.	23.970A.
10	Maximum PVMs power.	4.50kW.

Table-3: Wind power generating parameters.

S.No	Parameters	Value Units

1	Type.	Vertical
2	Rated Power(kW).	3.0.
3	Maximum Power(kW).	4.0.
4	nominal wind speed(m/s).	12.0.
5	Cutoff speed(m/s).	2.8.
6	Safety wind speed(m/s).	50.0.
7	Voltage at DC bus(V).	120.
8	Speed (rpm).	240.

Capacity of BBU is estimated for 24hrs working to operate 5.0kW motor (it can able to work for 4-5 days because of few hours per day are sufficient to fill the water storage tanks). Usually 48.0V batteries are widely available in market, hence the Ah rating of battery bank is estimated at 60% of initial SoC. Four numbers of batteries with each 48.0V are connected in series to make maintain proper voltage (i.e 192.0V). Below equation is used to estimate Ah rating of each battery.

$$I_b = \frac{5kW \times 24hr}{192V \times 0.6} \sim 1050\text{Ah}$$

Hence, each of 120Ah rated batteries are considered. To maintain rated Ah, 9 number of battery banks are connected in parallel.

3. SEAMLESS CONTROL FOR EMS

Because of weather circumstances, the electrical power delivered by wind and PVMs is not continuous. As a result, quick energy storage devices, such as batteries, are used to maintain energy balance between generation and load (i.e., motor) by adjusting voltage at the dc-link. Individual MPPTCs, together with their P&O algorithms, are associated with PVMs and wind systems. To reduce the more sensor units, the P&O algorithm is implemented on voltage at dc-link, thus there is no requirement for voltage monitoring at the PVMs and wind generator. Due to the necessity of a constant voltage for the PMDC motor to maintain a steady speed, the dc-link voltage is regulated by the charging and discharging current of the BBU through a bidirectional circuit. The voltage difference between the reference command (240.0V) and the dc-link is sent into the PI controller to generate the reference current of the BBU (i*b). By comparing the actual and reference currents of the BBU, the appropriate pulses are generated for the switches of the DC to DC circuit (i.e., Q3,4) via the hysteresis current loop. The BBU's SoC signal is combined with switches to prevent both overcharging and draining. The minimum limit of SoC is set at 5.0% (i.e., 0.05), while the top limit is set at 95.0%. When the SoC reaches its top limit, the charging switch (Q3) is turned off, and to maintain power balance, PVMs and Wind perform deloading operations by turning off their MPPT converters. In order to uphold the equilibrium of power, it is necessary to deactivate the discharging switch and disconnect the motor from the dc-link by opening switch (T) when the SoC reaches its minimum threshold. When the motor is unplugged from the dc-link, the BBU begins to charge. To prevent unnecessary wear and tear on the motor, it will not be turned on and off repeatedly. Instead, it will be reactivated using switch (T) once the State of Charge (SoC) reaches 20.0%, provided that the water level in the tank has not yet reached 98.0%. Once the water level reaches its maximum and Signal A is '1', the motor will be automatically turned off, regardless of the SoC level. Nevertheless, in order to prevent frequent activation and deactivation of the motor in instances where the water level drops below its upper threshold (A will be '0'), the controller will pause until the water level decreases below its lower threshold B (B will change to '1' if the water level falls below 60.0% of the tank's capacity). The seamless controller that has been suggested can operate the motor-pump set by taking into account both the state of charge (SoC) and water level (A and B in Figure 5 in the results section). The seamless control unit is illustrated in Figure 3.

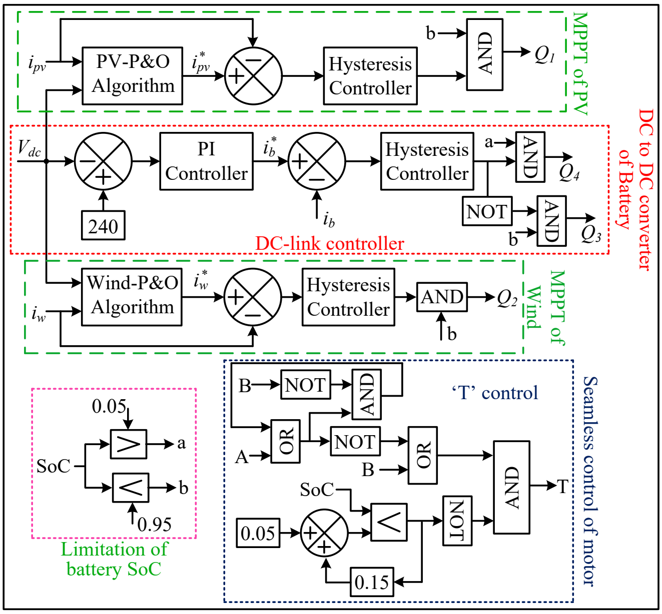


Figure 3: Proposed controller for seamless.

4. Outcomes of the Work

The system is tested by using HIL concept which is developed on the platform of OPAL-RT. To plan HIL, two OPAL-RT modules are associated one after the other. The plant is facilitated in OPAL-RT-1, and the regulator is unloaded in OPAL-RT-2. The research facility arrangement of HIL is introduced in Figure 4. The outcomes are done in framework for introducing in this part. Itemized HIL arrangement of proposed framework (Figure 2) is portrayed in Figure 5 with appropriate variety coding. The upper ('A') and lower ('B') level marks of water tank is likewise remembered for Figure 5which are not appearing in Figure 2. Once the water level reaches its maximum cutoff (i.e., 98.0%), the sign 'A' will be transform into '1'. On the other hand, when the water level falls below 60% of the tank limit, the sign 'B' will change to '1'. The acquired outcomes are helped out through another framework (PC) rather than oscilloscope for better introductions. Different boundaries and planning of framework parts utilized in this framework are taken on from [26-30].

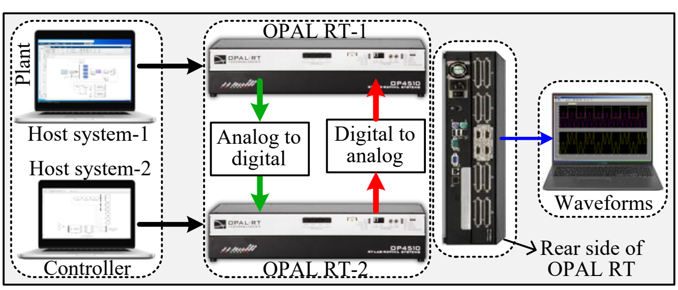


Figure 4: HIL laboratory setup with two OPAL-RT modules.

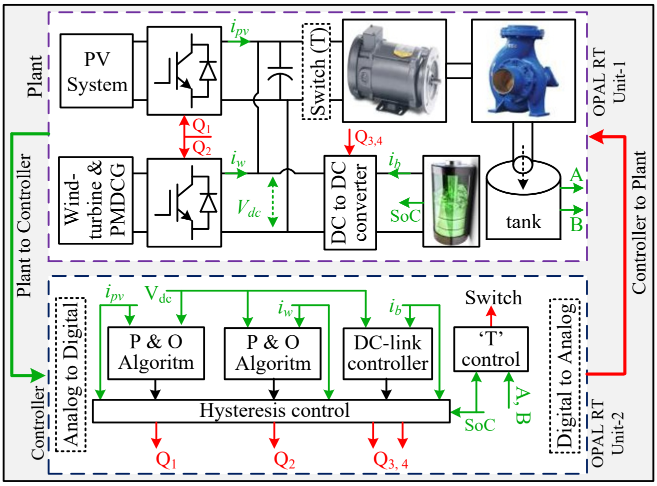


Fig-5: Implantation of WPM in HIL.

Consider the sun irradiation reduced from 1000to 400w/m^2 at t=2.0 sec, then increasing to 700w/m^2 at t=4.0 sec while the motor is operating the pump. A change in wind speed from 12 m/s to 7 m/s is applied to the identical situation at t=3.0 sec. The water level in the water tank was projected to reach its maximum at t=6 sec (A=1) throughout this operation. Figure 6 displays the aforementioned changes visually. The recommended controller, as illustrated in Figure 7, maintains appropriate EMS during this process. The PVMs and wind turbine create varying amounts of power in response to variations in solar irradiation and wind speed. Because this study takes into account a two mass drive train, wind turbine production is gradually reduced by lowering wind turbine speed. However, the power utilized by the engine remains constant until the tank level reaches its maximum (i.e., A=1. As a consequence, the battery reacts in accordance with the imbalance between total generation and motor load. Upon automatic shutdown of the motor at t=6.0sec, the BBU efficiently utilizes the surplus power generated by both PVMs and wind through the management of a bidirectional circuit. The BBU charging and discharging are regulated by a bidirectional circuit that maintains the DC-link voltage at its designated value (i.e., 240V), thereby determining the motor speed. Figure 8(a) depicts the DC-link voltage, which is set at 240V.The comparable SoC for the battery is also depicted in Figure 8(b). The charging and discharging processes of the BBU are clearly shown in Figure 8(b), as is the reaction of the BBU power, which is shown in Figure 7. The rising line depicts the battery's charging mode (increasing SoC), whereas the falling line represents the BBU's draining mode. On the contrary, the water level in the tank will increase steadily until it reaches the upper level indicator. Upon reaching the maximum water level, the engine will be automatically turned off by the designated seamless controller, allowing the tank to sustain a constant level until it is emptied through the outflow. Figure 8(c) depicts the tank's water level as well as the necessary operation areas.

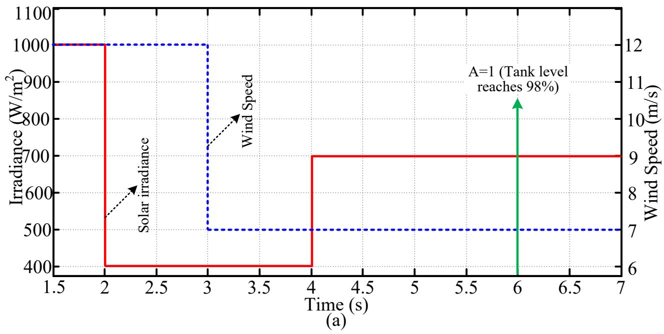


Figure 6: Changes in sun irradiation, speed of wind, 'A' (water tank level).

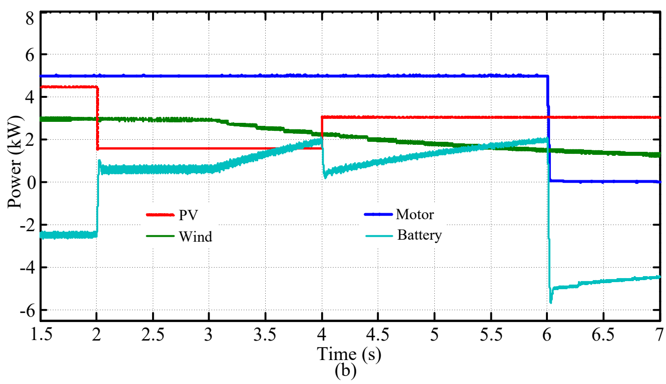


Figure 7: Various powers.

The control decision will be depends on both tank level and SoC of the BBU. Therefore, the motor will be run continuously with constant speed until water tank reaches its upper level until BBU having sufficient storage. Consider that the voltage reference signal in this operation is 240V, which is the rated voltage of the motor at 157 RPS speed. This speed, however, may be controlled by adjusting the DC to DC circuit's reference voltage signal. As a result, the motor continues to spin at 157 RPS until the single 'A' becomes a '1'.As a result, this is run as a continuous process. This procedure is performed indefinitely until the user sets fresh reference signals. Because of the system is designed to operate under user friendly mode.

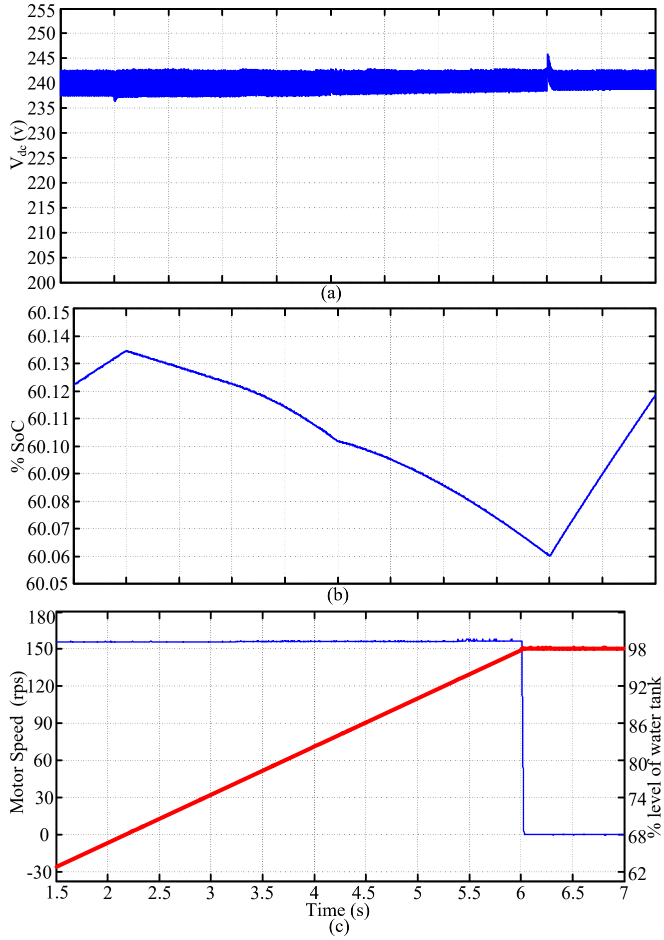


Figure 8(a) Voltage at DC-link, (b) SoC, (c) level of the water and speed of the motor.

5. Conclusion

In this work, an efficient EMS and a novel control method for a wind, battery-powered WPM is developed. Based on the battery SoC and tank water level, the proposed controller can able to functions automatically. Because the power provided by wind and PVMs is always changing, a bidirectional circuit is used to manage the BBU. To keep costs low, no extra converter is required to control the speed of the PMDC motor. However, the motor speed may be modified to fit our demands by adjusting the DC to DC circuit controller's reference voltage signal. The HIL of the proposed system is created with OPAL-RT modules, and the results are presented on a PC connected to the HIL. In this study, satisfactory findings are obtained and presented under a variety of conditions in order to validate the designed model.

References:

[1]. C. N. Bhende and S. G. Malla, “Novel control of photovoltaic based water pumping system without energy storage”, *International Journal of Emerging Electric Power Systems*, Vol. 13, Issue 5, Nov. 2012.
[2]. S. G. Malla, C. N. Bhende and S. Mishra, “Photovoltaic based water pumping system”, *IEEE: International Conference on Energy, Automation and Signal*, India, Dec. 2011.
[3] Saurabh Shukla and Bhim Singh, “Reduced-Sensor-Based PV Array-Fed Direct Torque Control Induction Motor Drive for Water Pumping”, *IEEE Transactions on Power Electronics*, Vol. 34, Issue: 6, pp. 5400-5415, June 2019.
[4]. M. N. Ibrahim, H. Rezk, M. Al-Dhaifallah and P. Sergeant, “Solar Array Fed Synchronous Reluctance Motor Driven Water Pump: An Improved Performance Under Partial Shading Conditions”, *IEEE Access*, vol. 7, pp. 77100-77115, 2019.
[5]. https://www.invensun.com/solar-panels/300w-solar-panel
[6]. https://www.windpowercn.com/products/16.html
[7]. https://www.greefenergy.com/post/87
[8]. Meghna and Y. K. Chauhan, "PV Water Pumping Using Integrated Quadratic Boost Zeta Converter," 2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC), 2018, pp. 120-125, doi: 10.1109/PEEIC.2018.8665640.
[9]. A. K. Wankhede, S. Pal, M. Singh, O. R. Gogte, A. Sharma and B. G. Fernandes, "Development of Efficient 5-HP BLDC motor for Solar water pump and performance comparison with Induction Motor counterpart," 2021 IEEE India Council International Subsections Conference (INDISCON), 2021, pp. 1-4, doi: 10.1109/INDISCON53343.2021.9582231.
[10]. S. G. Malla et al., "Whale Optimization Algorithm for PV based Water Pumping System Driven by BLDC Motor Using Sliding Mode Controller," in IEEE Journal of Emerging and Selected Topics in Power Electronics, doi: 10.1109/JESTPE.2022.3150008.
[11]. G. S. Chandrakant and S. K. Patil, "Designing of Controller for BLDC Driven Solar Water Pump," 2021 6th International Conference on Inventive Computation Technologies (ICICT), 2021, pp. 390-393, doi: 10.1109/ICICT50816.2021.9358629.
[12]. A. Tomar, P. H. Nguyen and S. Mishra, "SEPIC-MISO Converter Based PV Water Pumping System- An Improved Performance Under Mismatching Conditions," 2020 IEEE 9th Power India International Conference (PIICON), 2020, pp. 1-5, doi: 10.1109/PIICON49524.2020.9112907.
[13]. P. N. Dheeraja and E. S. Prasad, "Grid Interfaced Single Stage Solar Water Pump Using SRM," 2021 6th International Conference on Communication and Electronics Systems (ICCES), 2021, pp. 131-137, doi: 10.1109/ICCES51350.2021.9489110.
[14]. A. Waleed et al., "Solar (PV) Water Irrigation System with Wireless Control," 2019 International Symposium on Recent Advances in Electrical Engineering (RAEE), 2019, pp. 1-4, doi: 10.1109/RAEE.2019.8886970.
[15]. L. Nabila, F. Khaldi and M. Aksas, "Design of photo voltaic pumping system using water tank storage for a remote area in Algeria," 2014 5th International Renewable Energy Congress (IREC), 2014, pp. 1-5, doi: 10.1109/IREC.2014.6826981.
[16]. A. Bekraoui, M. Yaichi, M. Allali, A. Taybi and A. Boutadara, "Performance of Photovoltaic Water Pumping System in Adrar, Algeria," 2018 6th International Renewable and Sustainable Energy Conference (IRSEC), 2018, pp. 1-5, doi: 10.1109/IRSEC.2018.8702990.
[17]. R. K. Megalingam and V. V. Gedela, "Solar powered automated water pumping system for eco-friendly irrigation," 2017 International Conference on Inventive

Computing and Informatics (ICICI), 2017, pp. 623-626, doi: 10.1109/ICICI.2017.8365208.
[18]. H. A. Rabab'ah and Y. N. Anagreh, "Modeling and Simulation of Standalone WECS-PMSG for Water Pumping System," 2021 IEEE PES/IAS PowerAfrica, 2021, pp. 1-5, doi: 10.1109/PowerAfrica52236.2021.9543189.
[19]. M. Saputra, A. Syuhada and R. Sary, "Study of Solar and Wind Energy Using as Water Pump Drive-Land for Agricultural Irrigation," 2018 4th International Conference on Science and Technology (ICST), 2018, pp. 1-4, doi: 10.1109/ICSTC.2018.8528643.
[20]. A. K. Traoré, A. Cardenas, M. L. Doumbia and K. Agbossou, "Comparative Study of Three Power Management Strategies of a Wind PV Hybrid Stand-alone System for Agricultural Applications," IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, 2018, pp. 1711-1716, doi: 10.1109/IECON.2018.8591683.
[21]. A. Saidi, A. Harrouz, I. Colak, K. Kayisli and R. Bayindir, "Performance Enhancement of Hybrid Solar PV-Wind System Based on Fuzzy Power Management Strategy: A Case Study," 2019 7th International Conference on Smart Grid (icSmartGrid), 2019, pp. 126-131, doi: 10.1109/icSmartGrid48354.2019.8990675.
[22]. W. Obaid, A. Hamid and C. Ghenai, "Hybrid MPPT Controlled Solar/Wind Power System for Pumping System," 2019 International Conference on Electrical and Computing Technologies and Applications (ICECTA), 2019, pp. 1-4, doi: 10.1109/ICECTA48151.2019.8959772.
[23]. W. Obaid, A. Hamid and C. Ghenai, "Hybrid Solar/Wind/Diesel Power System for Water Pumping Application," 2019 7th International Renewable and Sustainable Energy Conference (IRSEC), 2019, pp. 1-6, doi: 10.1109/IRSEC48032.2019.9078183.
[24]. Z. Mousavi, R. Fadaeinedjad, H. Moradi, M. Bagherzadeh and G. Moschopoulos, "A New Configuration for Wind/Solar Water Pumping System Based on a Doubly Fed Induction Generator," 2020 IEEE Energy Conversion Congress and Exposition (ECCE), 2020, pp. 1891-1898, doi: 10.1109/ECCE44975.2020.9235941.
[25]. A. Nekkache, B. Bouzidi, M. S. A. Cheikh, Y. Bakelli, A. Kaabeche And A. Dali, "Optimal Sizing Of Hybrid PV/Wind Based Water Pumping System Considering Reliability And Economic Aspects," 2018 International Conference on Wind Energy and Applications in Algeria (ICWEAA), 2018, pp. 1-6, doi: 10.1109/ICWEAA.2018.8605087.
[26]. J. K. Singh, K. A. Jaafari, R. K. Behera, K. A. Hosani and U. R. Muduli, "Faster Convergence Controller With Distorted Grid Conditions for Photovoltaic Grid Following Inverter System," in IEEE Access, vol. 10, pp. 29834-29845, 2022, doi: 10.1109/ACCESS.2022.3159476.
[27]. O N Chandrasekhar, "Modified Grey Wolf Optimization Algorithm for MPPT of PV System under Partial Shading Conditions", International Journal of New Technologies in Science and Engineering (IJNTSE), Vol. 8, Issue. 5, pp. 1-6, May. 2022.
[28]. A. Dash, D. P. Bagarty, P. K. Hota, U. R. Muduli, K. A. Hosani and R. K. Behera, "Performance Evaluation of Three-Phase Grid-Tied SPV-DSTATCOM With DC-Offset Compensation Under Dynamic Load Condition," in IEEE Access, vol. 9, pp. 161395-161406, 2021, doi: 10.1109/ACCESS.2021.3132549.
[29]. Priyanka Malla, "Novel Control Technique for MPPT of PV Standalone System with TSK Fuzzy controller", International Journal of New Technologies in Science and Engineering (IJNTSE), Vol. 8, Issue. 8, pp. 1-7, Aug. 2022.

[30]. U. R. Muduli, K. A. Jaafari, K. A. Hosani, R. K. Behera, R. R. Khusnutdinov and A. R. Safin, "Cell Balancing of Li-ion Battery Pack with Adaptive Generalised Extended State Observers for Electric Vehicle Applications," 2021 IEEE Energy Conversion Congress and Exposition (ECCE), 2021, pp. 143-147, doi: 10.1109/ECCE47101.2021.9595601.