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An Improvement of Stability in Distribution Networkby Integrated Photovoltaic-Electric Spring System

R. Kalyan Kumar[1*], Syed Reshma[2], Dr. P. Sankar Babu[3]

[1]PG Student, Dept of EEE, SVR Engineering College, Nandyal.*
[2]Assistant Professor, Dept of EEE, SVR Engineering College, Nandyal.
[3]Professor & HOD, Dept of EEE, SVR EngineeringCollege, Nandyal.

Corresponding Email: [1]kvmpublications9@gmail.com*

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Abstract: The electricity grid's distribution system is a crucial component. Power quality issues in the distribution system have received a lot of attention in recent years due to the extensive integration of variable renewable energy generation. Modern digital grid technology, electric spring (ES), has previously been utilised to stabilise voltage and power in a system that relies heavily on unregulated or completely renewable energy sources. To control voltage and power, it has been recommended as a demand-side strategic approach. It has been suggested that electric springs (ES) might be used as a request technology to boost the reliability and efficiency of future power grids that rely heavily on intermittent renewable energies. At now, ES is mostly used for controlling grid voltage and service frequency. This study describes a method for controlling and balancing power in a newly integrated ES and PV system configuration, and it examines how this method may be used to achieve responsive supply equilibrium in electricity distribution networks. The suggested system allows for the maximum amount of collected PV power to be sent to the grid via the ES, while also actively regulating the energy usage of its ES-associated smart load in orderto maintain a constant supply-demand power balance. Because the smart-load powerassociated with the ES follows a suitable usage patterns to adjust for possible forecast failures of the PV power output, battery storage is unnecessary in the suggested architecture. Excellent performance of the suggested design method is demonstrated using Matlab/Simulink simulations.

Keywords: Electric Spring, Pv System, Bess, Power Quality, Mppt.

1. INTRODUCTION

Reliable and dependable transmission of electrical power is the backbone of every economy, and electricity is the kind of energy that may be used to satisfy the demand of citizens in both developed and developing nations. The most effective method of combating global warming

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is to address the fundamental sources of it: CO2 emissions from industries like transportation and electricity generating. Switching to RESs with electric vehicles looks to be the greatest solution for a sustainable future. Other potential responses to the exponential growth of GHG emissions include the substitution of electric vehicles for conventional ones, such as plug-in hybrid electric vehicles (PHEVs) and plug-in electric vehicles (PEVs), and the integration of battery energy storage systems (BESSs) or energy storage systems (ESSs) into the existing network. The production of renewable energies is more sporadic and unpredictable than that of traditional energy sources. Involving residential and industrial users in demand-side management (DSM) and demand response (DR) activities, the SG makes the integration of RESs and DGs feasible. DSM refers to the process of altering energy consumption patterns among end users by use of a variety of techniques, such as monetary incentives and pedagogical efforts. The primary objective of demand response programmes is to shift energy consumption away from peak times or to encourage users to reduce their consumption during certain times. In order to maximise the effectiveness of the power grid as a whole, DSM methods are used to the optimization of energy consumption patterns. Short-term adjustmentsin energy consumption made by end-users in reference to a price signal as from energy hourly market or a trigger triggered by the electricity grid operator are known as "demand response" (DR) schemes. The term refers to a shift in energy use by a customer of an electric company that helps balance supply and demand. When it comes to power, DR focuses on modifying use rather than generation. However, asking people to plan their energy consumption in a way that makes them uncomfortable is just unrealistic.

In order to improve the power supply-demand balance in a distribution network, this project deploys a DSM application utilising electric springs (ES). Grid voltage and frequency stability is where ES was first put to use. Later studies have expanded ES's use by employing a variety of circuit topologies to realise increasingly complex capabilities. Original ES (ES- 1), ES with battery (ES-2), and back-to-back ES are the three main varieties of proposed ES (ES-B2B). When ES-1 is serially attached to a non-critical (NC) load, it may directly offer reactive power compensation and indirectly alter the NC load's active power consumption. ES-2, an expansion of ES-1 that includes battery storage, significantly increases ES's usable range by enabling bidirectional active power flow. The shunt (grid-coupling) and series ES configurations are both used in ES-B2B at the same time. The ESB2B not only reduces the expense of ES-2's battery storage, but it also significantly increases ES's operational range. This research introduces a novel approach for combining a global PV power system with an ES and its accompanying NC load. The suggested PV-ES system still executes the DSM inthe same way that the original ES did, by simply altering the voltage of the NC load. This PV-ES system, however, represents a novel configuration in contrast to the previously stated ES systems, since it allows for maximum PV power harvesting and precise control of the active energy usage of the system using a new voltage control approach. Both the integrated PV power's intermittency and the power supply and demand imbalance may be mitigated by the PV-ES system.

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2. SYSTEM METHODOLOGY

Electric springs can provide real-time Demand Side Management without any of the complications involved with information and communication technology. Insightful theory understanding the behaviour of mechanical springs has been used to form the foundation for electric spring, thus the name. In Fig. 1, we see a diagrammatic representation of their functional similarity.

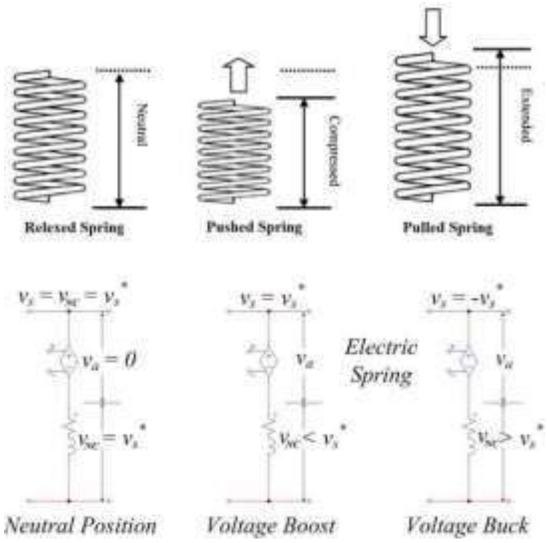

Fig.1: Comparison types of ES and Mechanical spring.

When it comes to ESs, both the CLs and NCLs are represented as continuous power loads. These ESs differ from those detailed in their operating principles due to the unique featuresof the loads they must manage. ES-equipped NCLs are used in the non-constant power configuration as a form of demand response equipment. In this situation, the NCLs can have their active and reactive capabilities modified to suit certain needs. Research on NCLs with ESs of the constant-power type is conducted with the aim of improving their ability to supply voltage regulation operations to the grid system. Although some of the fundamental ES operation equations remain valid, others have changed.

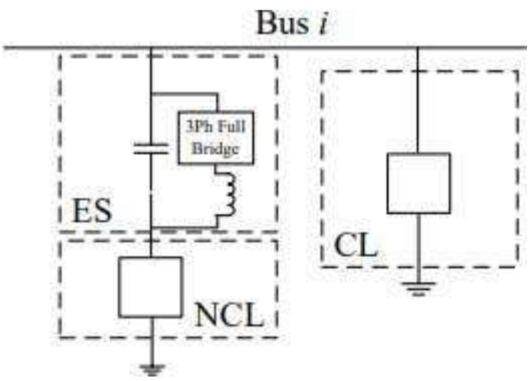

Fig.2: Topology of ES connection.

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Referring to Fig. 2, the ES is set up in between the NCL and the bus. By changing the voltage output from the ES, the bus voltage may be maintained at its nominal value. It's important that the voltage vector at the ES's output align perpendicularly with the current vector at the NCLs' connections. In this way, an ES's power converter's DC link voltage may be kept constant, allowing the ES to be run constantly without the need for any energy storage components. A lower initial investment and more potential for real-world ES implementation result from this particular operational feature.

Constant current flows via ES's DC power supply,

$$P_{Dc} = P_o = V_{DC} I_{DC}$$

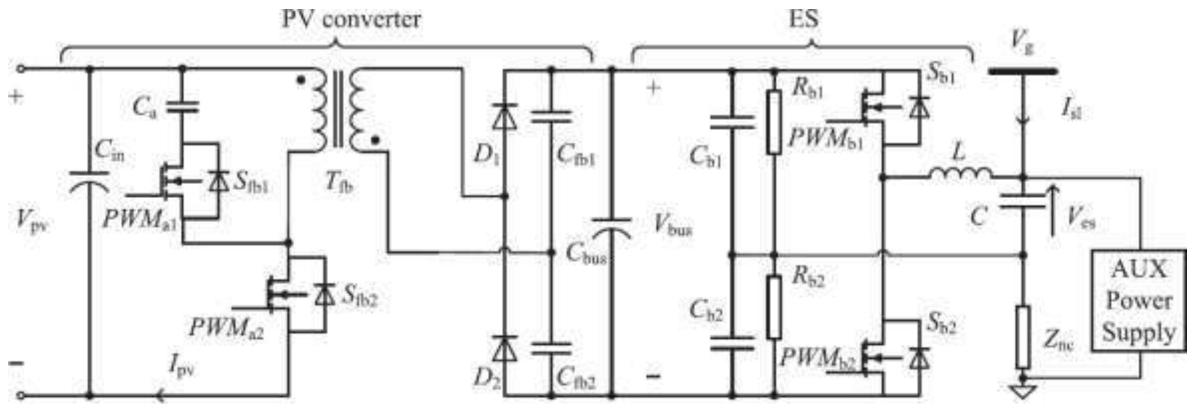

Fig.3: The suggested PV-ES power architecture.

Schematic of the power stages of the planned PV-ES system. An active clamp flyback dc/dc converter is utilised for the PV interfacing power converter, which boosts the voltage of the PV panels from their nominal value to the dc-bus voltage under maximum power point tracking (MPPT) control (Vbus). In Fig. 3 we see the components of a typical flyback dc/dc power converter, which consist of the transistors T1, Sa2, the capacitors C1 and D1. To create an active clamp circuit, Ca and Sa1 are introduced to the converter. D2 and C2 are added to create a voltage multiplier circuit, which effectively doubles the voltage conversion ratio. For maximum power point tracking, this flyback converter measures both the input voltage (Vpv) and input current (Ipv).

3. SIMULATION RESULTS

Here, we first apply the suggested control mechanism to a PV-ES system for 0.4 s, a time period that was compressed from an original 1 s recording. Second, the PVES system is compared to the standard PV plus BESS (PV+BESS) solution and the three distinct ES variants already in use.

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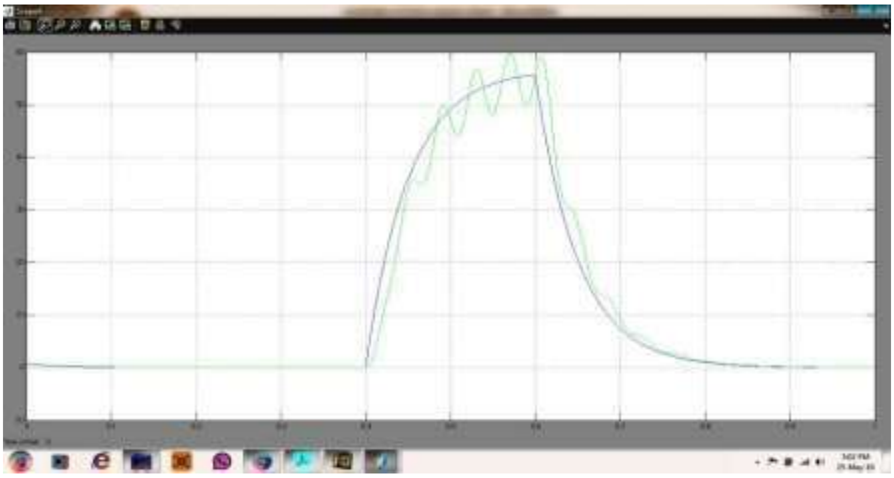
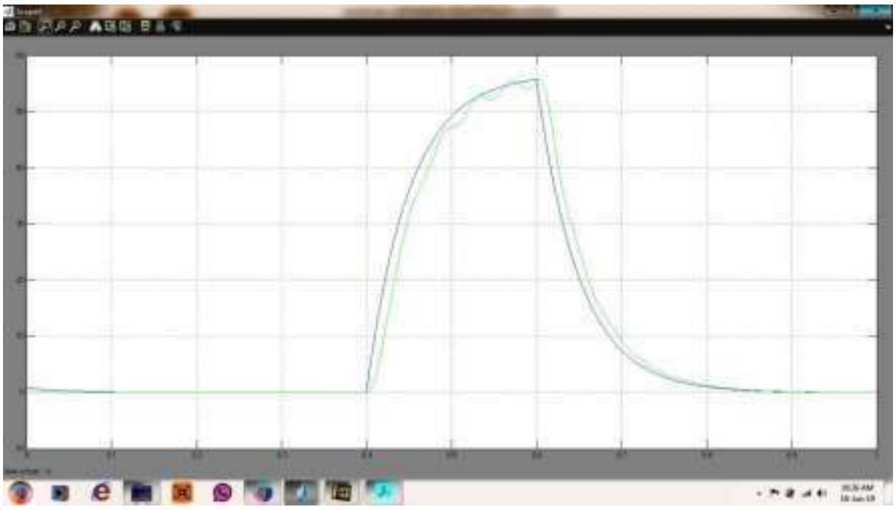
Case-A: Power Profiles



Existing system



Proposed system

Fig. 4 The power profiles of the predicted PV power (*P*pv_Ref) and the actual PV power(*P*pv).
In Fig. 4 we see a depiction of the output profiles of the referenced and real harvested PV power (Ppv Ref and Ppv) that were utilised in the simulation. Solar irradiance data is used in conjunction with a moving average approach to anticipate the PV power output profile. Net demand side power is used to determine a basic reference for demonstration purposes, even though the supply - side power standard in practise may be projected based on a wide rangeof facts and goals. Zcl and Znc are assumed to be constants during the test period to focus attention on the power flow regulation of the PV-ES in the presence of variable PV power.

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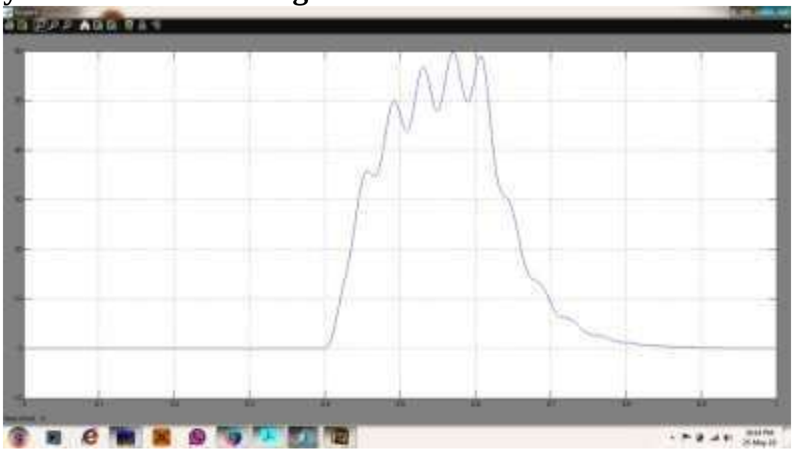
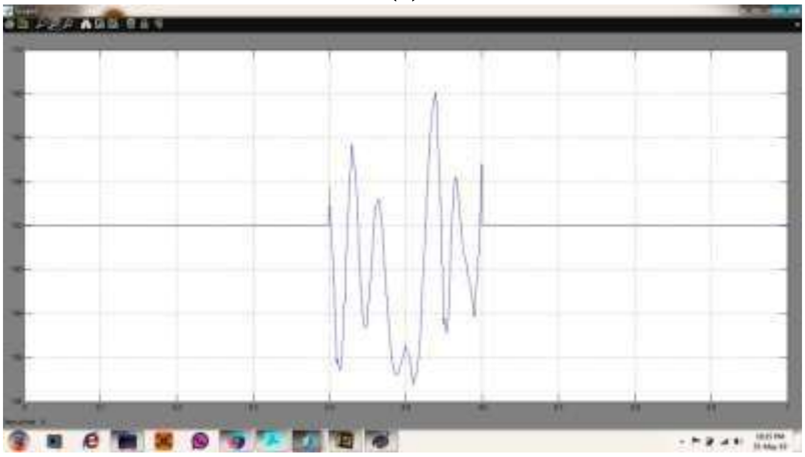
Case-B: Pv-Es System in the First Stage



(a)



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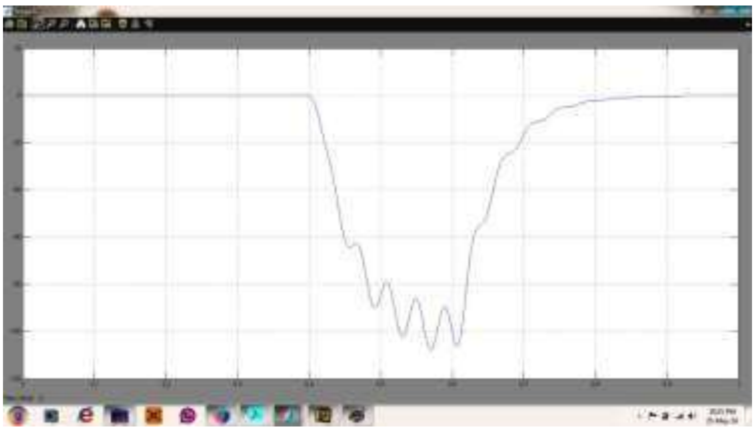

(c)

Existing system

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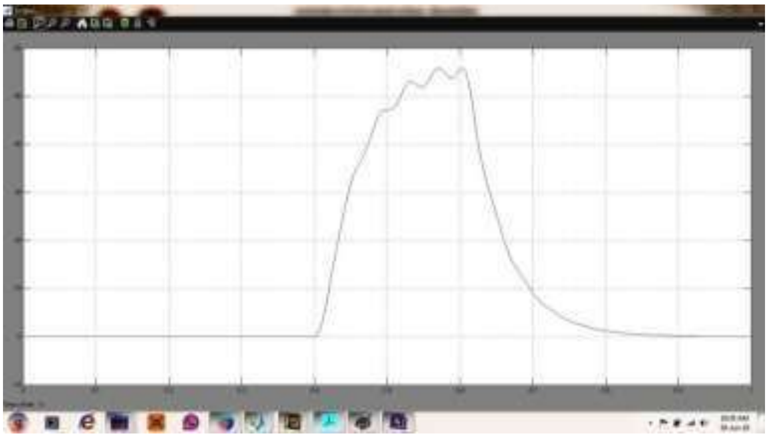
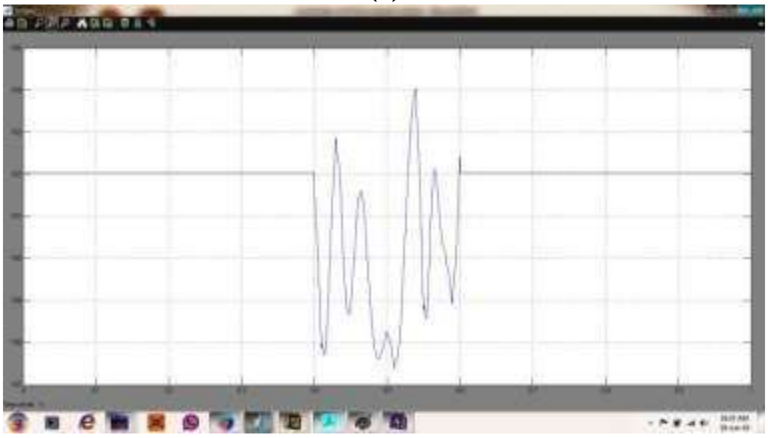
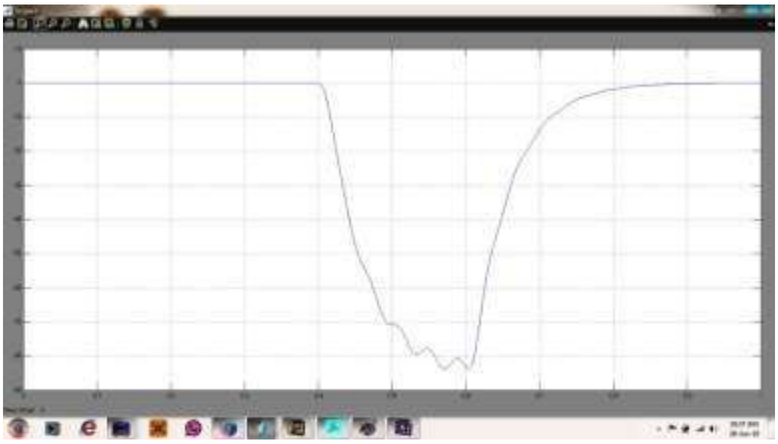


(a)



(b)



(c) Proposed system

Fig.5. Simulation results of the PV-ES system in the first stage. (a) The active power

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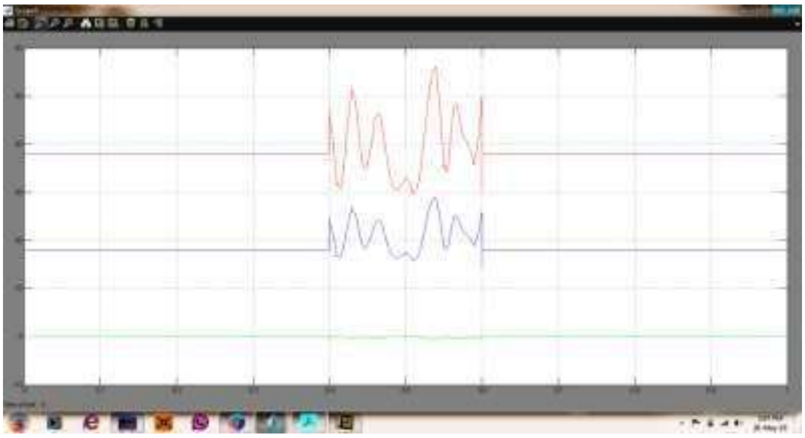
delivered by the ES (−*P*es). (b) The ES reactive power (*Q*es). (c) The NC load power (*P*nc).

The initial stage simulation results are displayed in Fig. 5. Between times t = 0 s and 0.4 s, and t = 0.6 s and 1 s, when solar energy is unavailable, the PV-ES system is inactive, and the demand-side supply is kept at its nominal value. Active power (Pes) supplied to the grid by the ES is shown as a function of time in Figure 5a. With the lossless converter assumption in mind, the dotted line in Fig. 5a (representing the actual harvested PV power) closely matches the shape of the Pes waveform. To demonstrate that the NC load is actively working to adjust the forecast inaccuracy of the PV power, we displayed its active power consumption in Fig. 5b, together with the PV and ES configurations. Without a doubt, the NC load power is dynamically adjusted near to, but not quite at, the rated capacity (160 W). A graph depicting the reactive power carried by the ES is also provided in Fig. 5c. Capacitive reactive power characterises ES, as shown by the polarity's negative value. The reactive power of ES can be adjusted inductive or capacitive by adjusting the value of Pg Ref. Here, the capacitivereactive power is selected at random.

Case-C: Three Types of Es Systems (Es-1, Es-2, and Es-B2b) For Comparison



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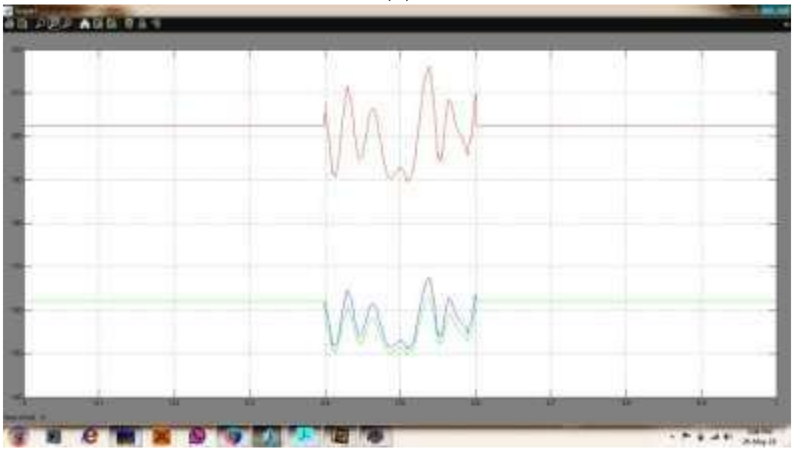
(a)



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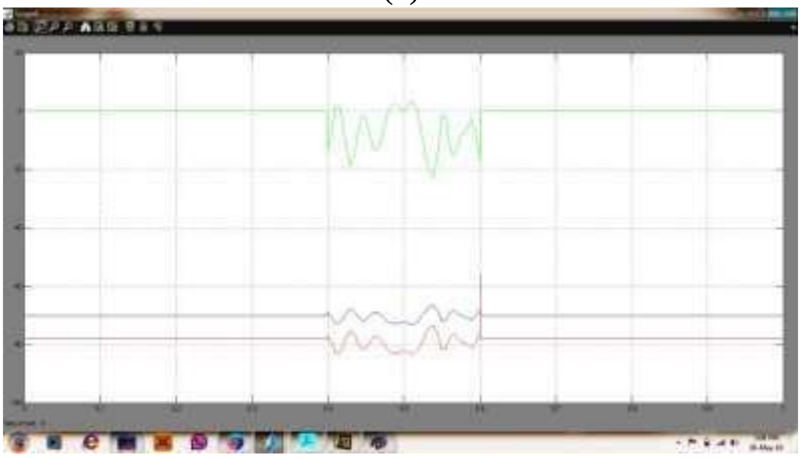
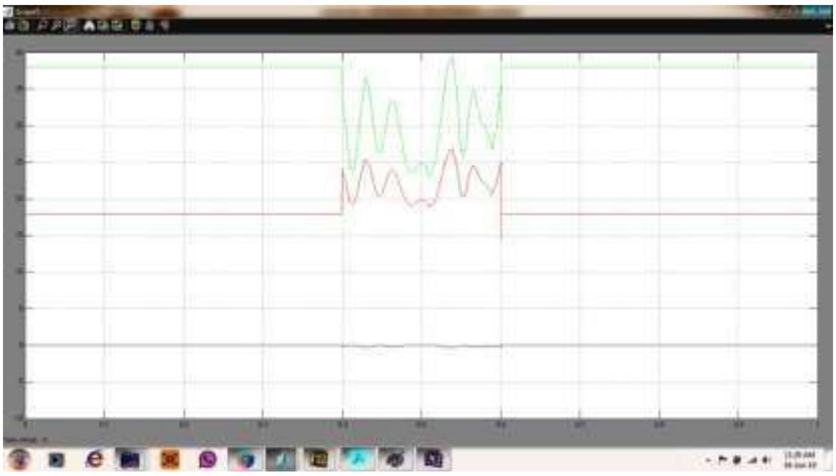


(c)Existing system



(a)

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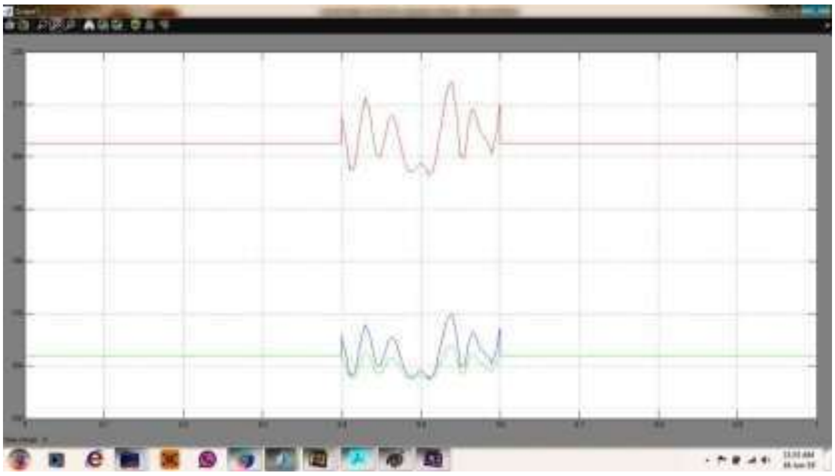
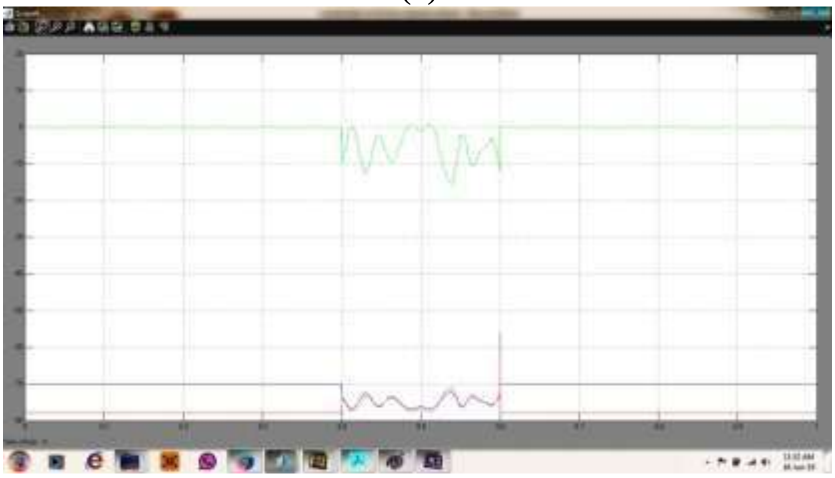


(b)



(c) Proposed system

Fig: 6. Simulation results of the three types of ES systems (ES-1, ES-2, and ES-B2B) for comparison. (a) The active power delivered by the ES systems. (b) The reactive power consumed by the ES systems. (c) The NC load power in the ES systems.

The PV-ES system's goals as a power balancer are used as a benchmark for the other three ES systems' aims. In addition, both the ES-2 and the ES-B2B are factory-set to maintain a power factor of 0.9 for the smart loads. Unlike the proposed PV-ES system, ES-2 and ES-B2B may be set up to regulate both active and reactive power usage at the same time. Three ES systems' period simulation results are depicted in Fig. 6. Figure 6a shows that since ES-1 can only offer reactive correction, its active power output is nearly negligible. Evidence from the features of ES-2 and ESB2B shows that these ES can keep up with the reference and the PV- ES with equal aplomb. There are noticeable outliers in the ES-1 profile, which are a result of the platform's limitations. The ES-1 can only reduce (but not raise) the active power usage of the

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sensible load from the asset value if the load is purely resistive (NC). Therefore, the smartload linked with ES-1 cannot use extra power to adjust for the variation when the real PV power is greater than the forecast value. Figures 6b and 6c show the NC load demand and ES reactive power, respectively, that corroborate this. Because of this, the suggested PV-ES has an advantage over ES-1 in terms of accomplishing the same goal. The functioning of ES-2 necessitates total energy from its battery storage, despite the fact that it can give I exact active power consumption management of the smart load similar to the PV-ES and (ii) controlled reactive power compensation superior to the PV-ES. Based on the maximum 50-W PV generation and the 160-W NC load illustrated in Fig. 6a, ES-2 needs around 38 W. Furthermore, as can be shown in Fig. 6b, the NC load is substantially compromised by the functioning of the smart load related to ES-2. In this case, the power of the NC load is 198 W in the static state (to regulate the power factor) and 224 W in the active state. As a conclusion, while ES-2 can accomplish the same goal as the proposed PV-ES, it does so at a greater cost and with lower performance of the NC load. When compared to the other two ES systems, however, ES-B2B fares the best. Power for the series section of ES-B2B is drawn directly from the grid via the shunt ES, as illustrated in Fig. 6a, with the same degree of precise active power management as the smart load. Based on operational power flow, ES- B2B is more flexible and efficient in limiting power usage than ES-2. Figures 6a and 6c show that the active/reactive power transmitted via ES-B2B is less than that transmitted via ES-2. The power fluctuations of NC load are also regulated to the same degree as PV-ES. As a power balancer, ES-B2B functions similarly to the planned PV-ES. In contrast to PVES, however, ES-B2B has a substantially greater implementation cost. Compared to the ES-B2B system, which requires a back-to-back converter, an isolation transformer, and a separate PV inverter, the proposed PV-ES offers a compact structure that includes both the PV converter and the ES inverter. In conclusion, the suggested PV-ES device works as well as, if not greater than, the other available solutions in terms of stabilising the demand-side power that is impacted by the variable PV power. However, it stands out as a viable option because tothe cheap setup time of its circuit configuration and the absence of a battery. If PV-ES is integrated into a power system that already makes use of ESS, diesel generators, and load control methods, the system will gain the following advantages: Since PV-ES offers continuous power flow correction as a smart load, it will be suitable with most load control schemes; furthermore, PV-ES may aid in lowering the rated power needed for ESS and diesel units by smoothing out PV power fluctuations.

4. CONCLUSION

In this paper, a PV-ES system is implemented in electricity distribution networks with a penetration level of PV power generation to aid in grid stabilisation. The suggested PV-ES can harvest the variable MPPT PV power without engaging battery storage, and it can also adaptively manage the active energy consumption of the ES-associated sensible load at the same time, thanks to the load - flow study and implementation design in the single-phase power system. In terms of both performance and cost, the suggested PV-ES system is demonstrably superior to both the status quo and solutions based on older generations of ES. The simulation

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findings show that the problem of power imbalance, which may be due to an inaccuracy in PV power estimation, may be fixed. It has also been shown that the system's dynamic behaviour may be optimised by demand-side management in light of the smart loadassociated with ES.

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