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Design & Simulation of PV Grid system with Dispatchable Supercapacitor

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Abstract
This paper presents a reliable, extended range power storage for grid connected PV systems. The power supply consists of solar PV source, a battery and Super capacitor (SC). Main source of power is battery, and is connected with super capacitor. These are connected at the starting and transient phase like overloading. Photovoltaic cell works for the steady condition. The total effect of such arrangement is to improve travel range, reduced size of battery , enhanced excellent response during overloading condition and improved battery life .Better performance which gives optimal use of energy, smooth ride and minimum size of sources of energy. Many stand-alone photovoltaic systems need storage device for providing steady state energy to the load when photovoltaicirradiation is not sufficient. Generally, Batteries are used for such application. Thus, providing a large peak current, like starting of motor, degrades plates of battery, results in devastation of battery. An alternate solution of providing heavy current is to connect battery with super capacitors forming an hybrid energy storage system, for which battery could provide steady state energy also the super capacitor can provide the peak power to connected load. A secondary source, solar panel module is available to charge battery and super capacitor

Key Words:-Large-scale PV system, Dispatchablegeneration, Centralized grid-connected, Battery, Supercapacitor

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Introduction

As the cost is continuously decreasing, photovoltaic (PV) generation has become one of the most important renewable energy sources and is being widely used. Grid-connected solar photovoltaic power plants are being installed globally at a fast pace. However, for present photovoltaic power technologies, the output power depends upon the availability of illumination and therefore may not always be constant. Problems brought by photovoltaics to the security stabilization and control of power grids are progressively appearing [1], especially when high permeability photovoltaics are accessed in a system. Additional regulations and standards are expected to be imposed.

A possible solution for regulating the natural oscillating output power of photovoltaics is to integrate them with an energy storage system [2]. Through a reasonable energy storage control strategy, the charge and discharge of energy storage can be controlled dynamically, which will makeit possible to balance the energy of power grids and optimize system operation [3,4]. Used asan emergency power supply and energy buffer device, energy storage can not only balancephotovoltaic output fluctuation, but also improve photovoltaic capacity permeability and utilizationlevel, optimize the power grid economics, and improve the stability of the entire photovoltaic system [5]. Reasonable storage configurations and control strategies are therefore of great signifycance for photovoltaic and energy-storage hybrid systems in high photovoltaic penetration scenarios.

At present, most research on photovoltaic and energy-storage hybrid system focuses onpredictive techniques, and control methods for modular converters and voltage regulators [6–9].

Control strategies of different time scales are also taken into consideration [10]. Some researchershave studied storage charge and discharge control strategies based on hybrid energy storage.Tummuru proposed a fast acting DC-link voltage-based energy management schemes for a hybridenergy storage system (HES) fed by solar photovoltaic (PV) energy. Using the proposed control schemes, fast DC-link voltage, effective energy management and reduced current stress on batteries are achieved [11]. Feng proposed a HES composed of lithium-ion batteries and supercapacitor that can be incorporated in the PV-based system to complement the supply-demand mismatches by using a multimode fuzzy-logic power allocator [12]. Ciobotaru proposed a power management strategy of a hybrid energy storage system (HESS) to reduce the required power rating of the supercapacitor bank (SCB) to only one-fifth of the vanadium redox battery (VRB) rating and to avoid the operation of the VRB at low power levels [13].

Based on the aforementioned review of previous works, it can be found that most research only considers the control effect of each storage device or hybrid storage in a centralized structure and little work has been done to study the configuration pattern of different energy storage systems. Configuring different energy storages reasonably and hierarchical control strategies still need further study.

This paper proposes an energy management strategy based on a hierarchical storage structure. Based on the equivalent circuit models of PV, battery and supercapacitor, the paper introduces a typical distribution network structure with hierarchical storage, and then analyzes the control effect of batteries and supercapacitors. An improved configuration structure is proposed and its control method when some constraint conditions are taken into account is discussed. What's more, to solve the problem brought by centralized management of mass batteries, a three-layer management structure is introduced. Finally, simulation is carried out to verify the control effect.

The rest of the paper is organized as follows. Section II outlines supercapacitor Modeling. Constraint Condition to analyze power output of photovoltaicsystem in Section III. The Proposed Methodology is analyzed in Section IV. Section V is concentrated on the simulated result of supercapacitor. The conclusions are given in Section VI.

Supercapacitor Modeling

The supercapacitor considered in this paper is double-layer capacitor; its equivalent model circuit is shown in Fig 1. This model provides three different time constants to model the different charge transfers, which provides sufficient accuracy to describe the terminal behaviour of the supercapacitor for the desired span of 30 min.To reflect the voltage dependence of the capacitance, the first branch is modeled as a voltage dependent differential capacitor. The differential capacitor consists of a fixed capacitance C_{i0} anda voltage dependent capacitor $C_{i1}\times V_{ci}$.

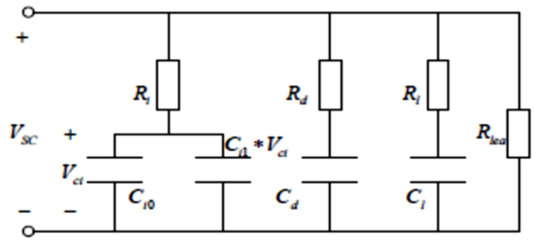

Fig 1 Equivalent Circuit of Supercapictor

A resistor, parallel to the terminals, is added to represent the self-discharge property. The first or immediate branch, with the elementsR_i , C_{i0} and the voltage dependent capacitance C_{i1} in [F/V], dominates the immediate behaviour of the supercapacitor in the time range of seconds in response to a charge action. The second or delayed branch, with parameters $R_d$and C_d, dominates the behaviour in the range of minutes. Finally, the third or long term branch, with parameters R_1 andC_1, determines the behaviour for times longer than 10 min.

Constraint Condition

The above discussion doesn't include photovoltaic and energy storage constraints, but actually the parameters of devices are important and the system restrictions need to be taken into account when the formulating control strategies.The system power balance constraint is:

$$\sum_{i}^{n} P_{PVi} + \sum_{j}^{l} P_{ESj} + P_{SPG} = P_{L\_AC}$$

Where $P_{PV}$the photovoltaic output power, n is the total number of photovoltaics, P_{ES} is the output power of each energy storage. In this case, it's only a battery. When it's positive, energy storage is discharging, while when it's negative, energy storage is charging. I is the total number of energy shortage devices. $P_{SPG}$is the tie-line power of other grids. $P_{L_AC}$is the AC load power.

The bus bar voltage constraints is

$0.95U_e$<U_{SUS}< 1.05 U_e

Where $U_e$the rated bus is bar voltage and U_{SUS} is actual bus bar voltage.Photovoltaic output constraints is:

$$\bar{P}_{PVimin} < P_{PVi} < \bar{P}_{PVimax}$$

Where $\bar{P}_{PVimin}$ and $\bar{P}_{PVimax}$ are the inferior and superior power limits for the photovoltaics, respectively.Battery and supercapacitor power constraints is

$$P_{Bmin} < P_B < P_{Bmax}$$

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$$P_{SCmin} < P_B < P_{SCmax}$$

Where P_B is the actual battery power, P_{SC} is actual supercapacitor power. P_{Bmin} and P_{Bmax} are the inferior and superior power limits of the batteries , respectively. P_{SCmin} and P_{SCmax} are the inferior and superior power limits of the supercapacitor respectively.

Proposed Methodology

As indicated from the flow chart of Proposed Work, supercapacitor is used as power bank. After checking minimum voltage power charging & discharging of capacitor continues. If charging voltage is above the threshold voltage, then stop the capacitor charging. In this flow chart it is indicated that supercapacitor used as power source. After checking threshold voltage use batteryto power Starter in Conjunction with Capacitor. If there is no power requirement, disconnect capacitor and battery from starter. Then again check all the connections with maximum voltage.

The bus link capacitor is used in DC to AC inverters to decouple the effects of the inductance from the DC voltage source to the power bridge. The bus link capacitor also plays a role in reducing the leakage inductance of the power grid.

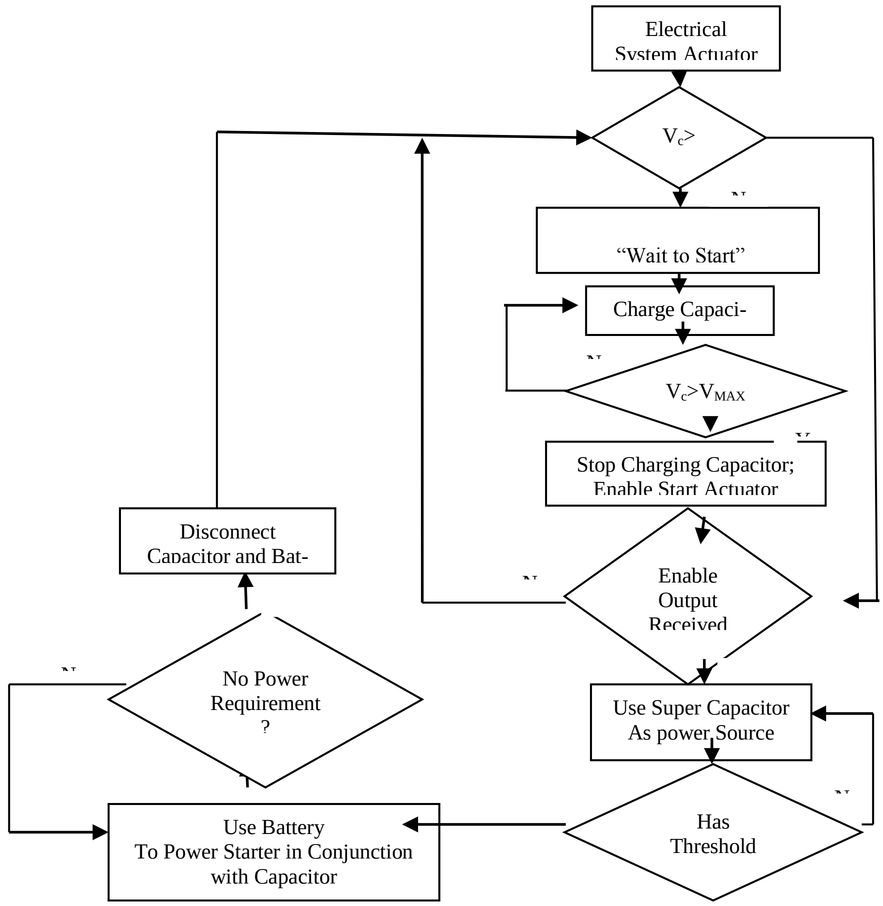

Fig 2 Flow chart of Proposed Work

The main attraction has always been the low cost per farad associated with supercapacitors. The DC link capacitor is very important in the life time of the converter, and it should be kept as small as possible and preferably substituted with film capacitors. A lot of work has been invested into reducing the DC-link capacitance of inverters in order to replace supercapacitor capacitors with the more reliable, but also more expensive and larger film capacitors

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Result & Discussion

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The Simulink model is designed as shown in fig 3. Here supercapacitor is associated with PV model. Power supply is connected to PV grid through universal bridge.

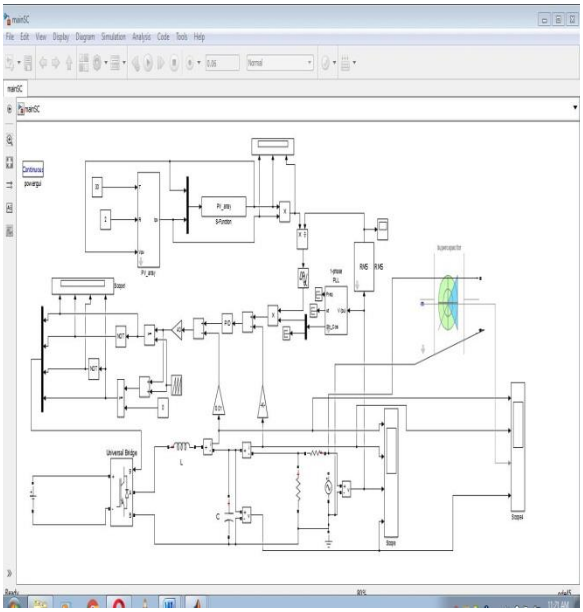

Fig 3 Simulink Model of PV grid System with Supercapacitor

The charging and discharging of supercapacitor as shown in Fig 4. There is two graphs in Fig 4 , top graph show input power supplied to supercapacitor and bottom graph show output power of supercapacitor. In the graph, capacitor firstly discharges & then charge up to a particular level. This level of voltage is 2000V.

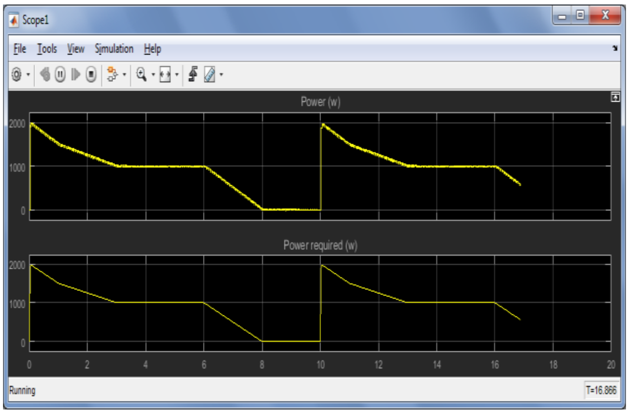

Fig 4 Input Output power of Supercapictor with Proposed Model

It can be clearly noted that when we use Our Super capacitor Module Power Injected follows closely to Power Required. As in result in base paper it is clear that battery powered system is very bad at injecting power into grid when it is need.

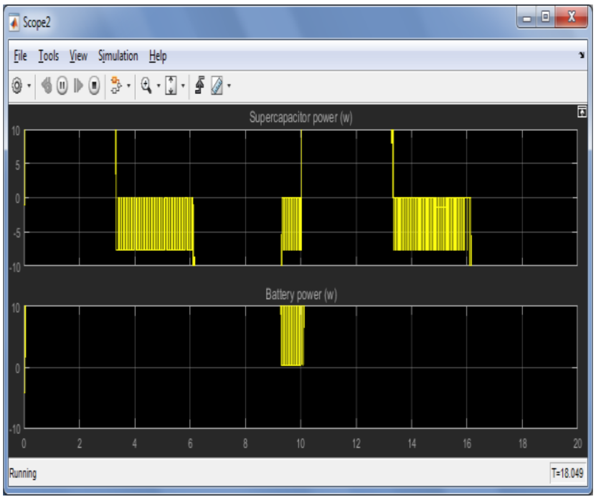

Fig 5 Current though Proposed Supercapictor

Current flow through batteries & supercapacitor is as shown in Fig 5. From the fig, it is clear that current in supercapacitor have more current low with respect to time.

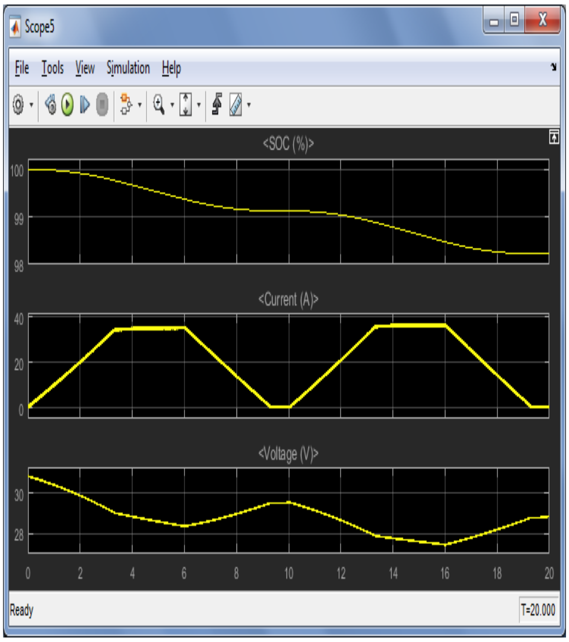

Fig 6 Battery State of Charge, Current and voltage of Proposed Supercapictor

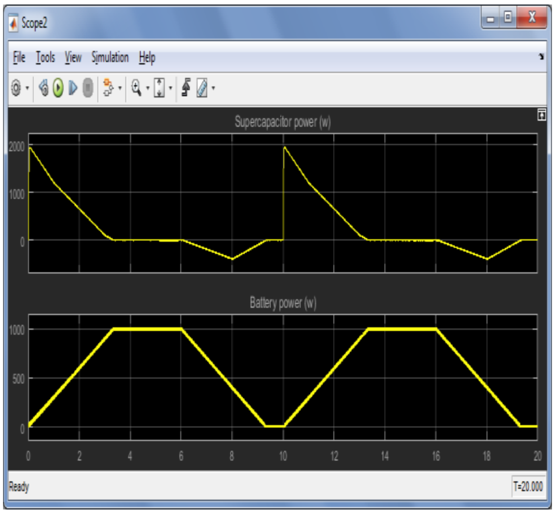

Fig 7 Battery power Vs Super capacitor Power

Fig 6 shows Battery State of Charge, Current and voltage of Proposed Supercapictor. Super Capacitor Provides Sharp Charge Storage and slow Discharge as contrast to battery, it is to be noted that the Super capacitor is charged only twice in this scenario at time T=0 and T=10 as compared to continuous charging to battery

Battery power Vs Super capacitor Power shown in Fig 7. Due to the high power density and the low energy density, the discharging time of the supercapacitor is very short and its response is very fast. The supercapacitor plays the role of absorbing the high-frequency power fluctuations from the PV and maintaining the voltage of the DC link in a proper range.

Conclusion

With the development of the renewable technologies,large-scale grid-connected PV plant has become a hot
topic. The conclusions are:
1) A centralized, large-scale grid-connected PV system with battery-supercapacitor hybrid electricity storage has been described. Taking advantage of their complementary characteristics, the batteries and supercapacitors have been used as the main and secondary storage devices to provide a high quality of supply and efficiency. The PV system was modeled in the MATLAB/Simulink and the control strategies demonstrated.
2) A sets of weather data were collected from an existing PV site and used as the input for the system to demonstrate its feasibility.
3) The simulation studies demonstrated that the proposed system could operate smoothly over the 20 hours test period. Using the storage system, the PV system was able to supply a continuous 20 MW of power to the grid as set by the centralized dispatch schedule.

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